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EFFECTS OF LONG-TERM EXPOSURE AMONG U.S. ARMY ARTILLERYMEN

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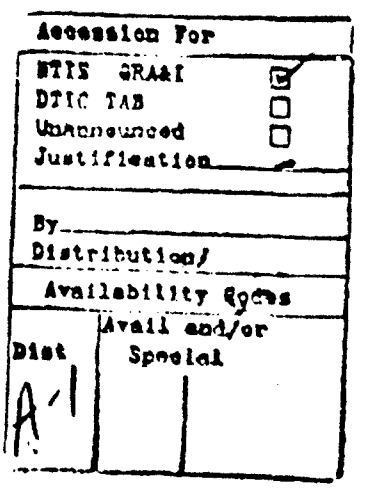
artillerymen having nonsignificant bone lead concentrations. The latter results might become statistically significant with larger groups, indicating the importance of measuring both blood lead concentrations, which provide a measure of recent exposure, and bone lead concentrations, which provide an evaluation of cumulative exposure.



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We appreciate the concentrated effort that the editor, David Nadziejka, applied to finalizing the report. He gave that extra push required for a job well done.

During the time that this program was being carried out, one of its co-authors, Dr. Robert P. Larsen, passed away. Studying the data base after his death brought sadness, but also brought memories of the good times we had together designing and testing the x-ray fluorescence instrument for in vivo measurement of bone lead concentrations. It was his input that gave us the confidence that we could succeed in this undertaking. We miss him.

NOTATION

Abbreviations

A	artillery (group)
FEP	free erythrocyte porphyrin
MI	military intelligence (group)
MM	median motor (nerve)
MS	median sensory (nerve)
NCV	nerve conduction velocity
NS	not significant
Pb-B	lead concentration in blood
Pb-S	lead concentration in bone
PEL	permissible exposure limit
PM	peroneal motor (nerve)
SD	standard deviation
SS	sural sensory (nerve)
UM	ulnar motor (nerve)
US	ulnar sensory (nerve)
XRF	x-ray fluorescence

Units

°C	degree Celsius
cm	centimeter
dL	deciliter
eV	electron volt
h	hour
in.	inch
keV	kiloelectron volt
m	meter
m^3	cubic meter
MeV	megaelectron volt
min	minute
mm	millimeter
mR	milliroentgen
mrem	millirem
ms	millisecond
ppm	parts per million
s	second
V	volt
y	year

Chemical Symbols

Ca	calcium
Co	cobalt
Pb	lead

LEAD EXPOSURES AND BIOLOGICAL RESPONSES IN MILITARY WEAPONS SYSTEMS: EFFECTS OF LONG-TERM EXPOSURE AMONG U.S. ARMY ARTILLERYMEN — FINAL REPORT

by

M.H. Bhattacharyya, J.H. Stebbings, R.P. Larsen,
D.P. Peterson, B.G. Oltman, Z. Liu, and G. Strejcek

ABSTRACT

The purpose of this study was to determine whether measures of lead exposure or responses to lead exposure (1) were greater in artillerymen than in control servicemen or (2) increased with increasing length of service in the artillery. The measures of lead exposure were blood lead concentration (Pb-B) and bone lead concentration (Pb-S), measured in vivo by x-ray fluorescence spectrophotometry. The lead responses evaluated were increases in free erythrocyte porphyrin concentration, increases in blood pressure, and decreases in nerve conduction velocity for three motor and three sensory nerves. Although the study did not achieve planned group sizes because of early termination, the results showed that lead exposures were low in all study subjects, that artillerymen had no greater exposures or responses to lead than did military intelligence personnel as controls, and that lead exposures and responses did not increase with increasing length of service among the artillerymen. Bone lead concentrations came the closest to distinguishing between artillerymen and military intelligence controls, showing a slight increase in Pb-S values for the newer artillerymen (5–8 y of service) over the corresponding controls and slightly more control subjects than artillerymen having nonsignificant bone lead concentrations. The latter results might become statistically significant with larger groups, indicating the importance of measuring both blood lead concentrations, which provide a measure of recent exposure, and bone lead concentrations, which provide an evaluation of cumulative exposure.

SUMMARY

MEASURES OF LEAD EXPOSURE

Blood Lead

- Blood lead (Pb-B) concentrations were low for all study subjects, with the mean value for artillerymen (A) not significantly greater than that for military intelligence (MI) controls when all subjects were considered: A, 4.2 ± 1.8 μg/dL (mean ± standard deviation [SD], n = 24), range 2.0–11.2; vs. MI, 4.2 ± 2.2 μg/dL (n = 21), range 1.7–11.0; p = 0.90.

- No significant differences were found between the two groups when each group was subdivided according to length of service or frequency distribution of values.

- A small increase in Pb-B values was observed with length of service for the MI controls, probably reflecting an increase with age. There was no increase in Pb-B values with years of service for the artillerymen.

Bone Lead

- Bone lead concentrations, measured from the ratio of the x-ray fluorescence (XRF) peaks of lead and calcium (Pb/Ca XRF ratio), were not significantly higher in artillerymen than in the controls when all subjects were considered: A, 0.124 ± 0.064 (n = 24), range, not significant to 0.241; vs. MI, 0.106 ± 0.072 (n = 24), range, not significant to 0.280; p = 0.63.

- This end point of exposure provided the only results indicating that artillerymen, especially those with the shortest length of service (5–8 y), may have had somewhat higher exposures to lead than the control personnel.

- The indication of greater exposure among the artillerymen was reflected in somewhat higher Pb/Ca XRF ratios for the artillerymen in the 5- to 8-y subgroup and in the greater frequency of Pb/Ca XRF ratios below the detection limit (not significant) for the MI group. These differences might have reached statistical significance if the group sizes had been larger, and they demonstrate the importance of obtaining bone lead concentrations, to evaluate cumulative exposure, in addition to blood lead concentrations, which reflect recent exposures.

MEASURES OF LEAD RESPONSE

Free Erythrocyte Porphyrins

- No significant differences were found in free erythrocyte porphyrin (FEP) concentrations between artillerymen and controls, regardless of years of service.
- FEP concentrations did not significantly increase with increasing length of service for either group, and there was no preponderance of high FEP values (an indicator of lead exposure) among the artillerymen.

Blood Pressure

- No significant differences were observed between artillerymen and controls in either systolic or diastolic blood pressure, regardless of years of service.
- Blood pressure values did not increase significantly with increasing length of service among artillerymen, and there was no preponderance of high blood pressure values (an indicator of lead exposure) among the artillerymen.

Nerve Conduction Velocity

- No significant differences were found between artillerymen and controls in the nerve conduction velocity (NCV) of three motor and three sensory nerves, regardless of years of service.
- When NCV values were converted to Z scores to correct for changes with age, there were no significant decreases in NCV with length of service among the artillerymen.

1 INTRODUCTION AND SCOPE

The U.S. Army Environmental Hygiene Agency has determined through field measurements that military personnel are exposed by inhalation to lead aerosols during the firing of armored vehicle weapons. In a recent study, scientists at Argonne National Laboratory determined that time-weighted average lead concentrations in air range from 1–2 $\mu g/m^3$ up to 600 $\mu g/m^3$ at crew member positions of an 8-inch howitzer during the firing of high-lead charges (Bh93). The OSHA permissible exposure limit (PEL) for lead is 50 $\mu g/m^3$ for an 8-h daily work period. Because the circumstances of military exposure to lead aerosols (sporadic, potentially high levels) differ from the circumstances of most civilian industrial exposures (continuous, predominantly low levels), military protection standards may need to be formulated differently from those recommended for industry. The need therefore exists to evaluate military exposures to lead and to recommend exposure standards that will provide the necessary protection to artillerymen over their careers and to crew members under combat conditions.

This report provides results from a follow-up study of chronic lead exposures and responses among career artillerymen who have potentially been exposed to weapons lead aerosols over much longer periods of time than the crewmembers in the acute exposure study previously published (Bh93).

Bone lead (Pb-S) concentrations were used as a measure of cumulative exposure to lead. The biological responses evaluated were changes in nerve conduction velocity and blood pressure. Blood lead and free erythrocyte porphyrin concentrations were also determined to provide an index of current exposures and a link to other studies in the literature. Decreases in nerve conduction velocity have been observed among persons occupationally exposed to lead (Se75, As80, Se80, Bo82, Si83, Co84, Je85). This response was chosen for study because of the obvious critical nature of the nervous system. Lead exposure has also been associated with a rise in blood pressure (Ba83). This response was investigated because (a) recent studies have focused on a blood pressure response to low levels of lead exposure (Fi88), (b) blood pressure can readily be measured, and (c) increases in blood pressure could influence an individual's long-term health.

The following questions were addressed.

1) Do career artillerymen have bone lead concentrations that are higher than those of a control group not in the artillery? Do their bone lead concentrations increase with increasing length of service in the artillery?

2) Are nerve conduction velocities lower or blood pressure values higher in the career artillerymen than in the control group?

3) Do nerve conduction velocities decrease either with increased bone lead concentration or with increased length of service in the artillery?

4) Does blood pressure increase either with increased bone lead concentration or with increased length of service in the artillery?

To answer these questions, three groups of artillerymen were selected at random from groups having averages of 5, 10, or 15 years of artillery service. Three corresponding groups of control servicemen were also identified for comparison. The study originally was to include approximately 60 artillerymen and 60 controls (20 men per group). Due to unanticipated changes in access to suitable study subjects, group sizes were restricted to 26 artillerymen and 25 controls in this study.

2 METHODS

2.1 OVERALL STUDY DESIGN

Lead exposures and responses were studied at Fort Hood, Texas, during July 1990 in two groups of U.S. Army personnel: 26 artillerymen and 25 military intelligence personnel. Study subjects were identified according to the number of years of continuous service in artillery or military intelligence units. The purpose of this study was to determine whether lead exposures and responses increased with length of service in the artillery for the categories of 5–8 y, 9–14 y, and 15 or more years. (Length of service was calculated as the test year (1990) minus the year of entry into the military. All subjects had continuous service either as artillerymen or as military intelligence personnel from the start of their service in the Army.) Artillerymen are exposed to lead in charges fired from various weapons systems, including high-lead charges fired from 8-in. or 155-mm howitzers (Bh93). The military intelligence personnel included as controls had similar lengths of service and age but were exposed to lead from weapons firing at levels much below those expected for the artillerymen.

The concentrations of lead in bone (tibia; measured in vivo by x-ray fluorometry [XRF]) and in the blood provided measures of past and current lead exposures, respectively. Potential responses to lead that were evaluated were free erythrocyte porphyrin (FEP) concentration, blood pressure, and nerve conduction velocity. The expected responses with increased lead exposure were increases in FEP concentration and blood pressure and decreases in nerve conduction velocity.

At the start of the study, each subject signed a consent form, answered a questionnaire, and had a first blood pressure measurement taken. At a scheduled time, each then had a second and third blood pressure taken (at the beginning and end of the measurement session, about 2 h apart), provided a blood sample, and had measurements made of the conduction velocities of six nerves and of tibia lead concentration. The questionnaire provided information on the nature of the study population, and the other samples and measurements provided ways to evaluate lead exposures and responses that might be correlated with length of service in the artillerymen.

2.2 STUDY POPULATION

As shown in Table 1, the artillery (A) and military intelligence (MI) groups were similar in age (29.8 ± 5.6 and 29.5 ± 5.7 y, respectively), marital status, education, and smoking and drinking habits. The differences between the groups for these descriptors were not statistically significant (Chi square test, $p > 0.1$). The study subjects generally were married; had at least a high school education; about 50% were smokers; and about 50–65% had habits of drinking 2–12 drinks on weekends and 1 or fewer during the week. The groups differed significantly in ethnic distribution, with black and Hispanic subjects more numerous in the artillery group.

2.3 BLOOD LEAD AND FEP ANALYSES

Blood samples were taken in the clinic at Fort Hood and were immediately frozen for shipment to Argonne. Blood lead (Pb-B) was analyzed by electrothermal atomic absorption using the method of Stoeppler et al. (St78). The detection limit for our assays was 1.2 μg/dL, defined as three times the standard deviation of the blank. This low detection limit was achieved by using a long time for aerosol deposition of the sample into the furnace. During the period when Pb-B was analyzed, our laboratory participated in the blood lead proficiency testing program offered by the College of American Pathologists (Skokie, Illinois). During the analysis period, we were on the list of laboratories approved for blood lead analysis by the Occupational Safety and Health Administration, U.S. Department of Labor.

Free erythrocyte porphyrins were analyzed using a fluorometric method which quantitates the fluorescence of FEP after a double extraction procedure (Pi73). (Erythrocyte porphyrins consist mainly of protoporphyrin IX. The words porphyrin and protoporphyrin appear to be used interchangeably in the literature when referring to this assay.) Fluorescence was measured on a Farrand Mark I spectrofluorometer (Farrand Optical Co. Inc., New York, New York). During the period in which our laboratory was involved in FEP analysis, we were enrolled in the Erythrocyte Protoporphyrin Proficiency Testing Program sponsored by the U.S. Department of Health and Human Services and managed by the Centers for Disease Control (Atlanta, Georgia).

2.4 BONE LEAD MEASUREMENTS

2.4.1 Instrument Design

An x-ray fluorescence (XRF) instrument was constructed by our group members (B. Oltman, with consultation from R. Larsen). The instrument consisted of a ^{57}Co source, a low-energy germanium detector, and the required preamplifier, amplifier, and multichannel analyzer system.

The source consisted of ^{57}Co electroplated on a palladium disk 2.0 mm in diameter and sealed in a welded stainless steel capsule with an 0.2-mm-thick window. A tungsten alloy was selected as the material to house the source. This housing was designed to provide for collimation and shielding of the beam in order to restrict the primary radiation to a conical zone near the detector face. The source holder was designed in parts, with one part being the collimator (Fig. 1). Three collimators were made with a hole of either 1.0, 1.5, or 2.0 mm in diameter to provide flexibility in the size of the beam. A "collimator" with no hole was made to block the beam when the source was not in use or was in transit. The assembled source and source-holder fit into a metal cup with a screw-thread case and top (Fig. 1).

The low-energy germanium detector (Canberra Inc. model GL0510R) had an active area of 500 mm^2 and a thickness of 10 mm. The window was a 0.5-mm thickness of aluminum. The energy resolution for the ^{57}Co source (122 keV) was

561 eV (full width of the peak at half its maximum intensity). The detector was fabricated with an ultra-thin, boron-implanted P+ outer contact on the front face and side wall. The N+ contact, a lithium diffused spot on the rear face, was less than the full area. Thus the capacitance of the detector was less than that of a planar device of similar size. The detector and preamp input were mounted in a vacuum chamber to protect the sensitive surfaces from moisture and other contaminants. The preamp energy rate was ≥ 200,000 MeV/s. The bias voltage was 1500 V.

Arms for the source and detector were made that permitted adjustment of both distance and angle, providing for a configuration that would give the lowest scatter background in the region of the lead fluorescence x-rays. The design of the support arms allowed ample freedom for adjustment to different leg sizes. The height of the study subject's chair was adjustable, allowing us to compensate for different bone lengths.

2.4.2 Dosimetry Evaluation

In collaboration with members of the Health Physics Division of Argonne, we placed thermoluminescent dosimeters at various locations on a leg phantom and obtained measurements of skin entrance dose, bone marrow dose, and other variables. A description of these evaluations was prepared for the Radiation Protection Officer at Fort Hood (Appendix B). The skin entrance dose to our 30-min measurement at 4 cm from the source was about 600 mrem (skin dose) or 450 mR (air dose). This is in range of the dose received from a single bitewing dental x-ray.

2.4.3 Procedures and Calculations

Measurements of tibia lead concentrations were made with the source 4 cm from the skin at the front face of the tibia and the detector at a 100° angle to the source. This configuration maximized the signal-to-background ratio. Data were collected over a 30-min period for each study subject. Bone lead concentration was expressed as the Pb/Ca signal ratio for each study subject, as explained below. Although several types of phantoms were made with known lead concentrations that would allow us to convert the Pb/Ca XRF ratios to known lead concentrations in bone, validation of the phantoms was not possible. However, conversion to lead concentrations was not necessary to compare the bone lead concentrations in the artillery and military intelligence groups, and thus the Pb/Ca XRF ratios were used directly to make the group-to-group comparisons.

Figure 2 shows the XRF spectrum obtained from a 30-min measurement of the plaster-of-paris tibia phantom that contained 1000 ppm Pb. From this spectrum, we determined that the counts in channels 595–602 are present in the full width of the peak at half its maximum intensity. Summation of the counts in this region provides the most sensitive measure of bone lead concentration, because the difference between the lead signal and the background signal is maximized. The inclusion of any more of the lead peak reduced the difference between the lead and the background signals.

To determine background for the lead peak in channels 595–602, channels on either side of the lead peak were chosen to define a straight line that would extend through the region of the lead peak. The channels chosen were 588–620 on the low-energy side and 606–610 on the high-energy side (Fig. 2). These channels start two standard deviations away from the center of the lead peak.

The following steps were involved in the computer program for determining bone lead concentration (refer to the computer output accompanying Fig. 3 to follow the results of each step for the 105-ppm standard, the spectrum for which is shown in Fig. 3.)

1) Define the background line determined by the counts in channels 588–592 and 606–620 (Fig. 3). List the counts in each background channel, along with the slope, intercept, and correlation coefficient of the background linear regression.

2) For each lead channel (595–602), list the number of total counts (from the spectrum), the number of background counts (from the background line), and the difference between the two (count minus background = net lead counts for each channel). Also provide a sum, for all lead channels, of the total counts and the background counts, with the standard deviation (SD) of each sum (SD = [total counts]$^{0.5}$). Calculate the difference between total counts and background counts, providing a sum of net lead counts in channels 595–602, with an SD value obtained by propagation of the error terms.

3) On the basis of the method of Potthoff and Whittinghill (Po66), calculate a value for G4 and use G4 to determine the probability that the total counts and the background counts are the same (i.e., that their difference, the net lead counts, is not different from zero). This method assumes a Poisson distribution of the total and background counts (i.e., the SD of the mean = [mean]$^{0.5}$).

4) Follow the above procedure (steps 1–3) to determine the net counts in the calcium peak, i.e., the coherent scatter peak caused by the coherent scattering of the incident ^{57}Co x-rays by the calcium in the bone. (The intensity of the coherent scatter [calcium] peak gives a measure of the amount of bone irradiated by the incident ^{57}Co x-rays.)

5) Calculate the ratio of the lead peak to the calcium peak. (Because the size of the lead peak is directly dependent on the amount of bone irradiated, bone lead concentration is obtained for each spectrum by calculating a ratio of the intensity of the lead peak to that of the calcium [coherent scatter] peak).

An example of a spectrum from the tibia of an artilleryman with a Pb/Ca XRF ratio of 0.102 is shown, with its analysis output, in Figure 4.

2.5 BLOOD PRESSURE MEASUREMENTS

Blood pressure measurements were taken on three separate occasions by an Army nurse. Diastolic and systolic pressures were recorded. Multiple measurements were taken to average effects of stress over three readings.

2.6 NERVE CONDUCTION VELOCITY MEASUREMENT

Nerve con luction velocity (NCV) measurements were obtained by David Peterson for six nerves on each individual using a TECA Model TD10MK1, Electromyography/Evoked Potential (EMG/EP) System (TECA Corp., Pleasantville, New York 10570). The motor nerves included the median (MM), ulnar (UM), and peroneal motor (PM) nerves; the sensory nerves, measured using antidromic stimulation, were the median (MS), ulnar (US), and sural (SS). Measurements of the MM, UM, MS, and US conduction velocity were obtained on the subject's dominant arm from elbow to wrist. Skin temperature was monitored on the plantar surface of the hand over the first dorsal interossei muscle using a skin thermistor connected to a Model 5800 electric thermometer (OMEGA Engineering, Inc., Stanford, Connecticut). The conduction velocity of the PM and SS nerves was measured on the contralateral leg; skin temperature was monitored from the medial surface of the foot, approximately 3 cm distal to the medial malleolus.

The motor nerves that we surveyed were mixed fast and slow fibers. The conduction velocity of the fast fibers was measured by using supramaximal stimulation, with a stimulus duration between 0.05 and 0.20 ms. The method of de Jesus et al. (De73) was used to adjust the individual NCV values for differences in skin temperature. Arm nerves were adjusted to 34 °C and leg nerves were adjusted to 33 °C. To adjust NCV values for differences in age of the subjects, regression lines for changes in NCV values with age were obtained from the literature for the MM, MS, UM, and US nerves (Bu75, Ni73), along with SD values for each line. From these regression lines, a Z score was obtained for each NCV value by calculating the number of standard deviations that the measured NCV value was from the NCV value predicted from the regression line and the individual's age. A comparison of mean Z scores for the two groups allowed an evaluation of group-to-group differences after adjustment for expected decreases in NCV with increasing age. The regression lines were (Bu75, Ni73)

MS: $74.7 - 0.22 \times \text{age}$ (SD = 4.3 m/s)
US: $78.3 - 0.18 \times \text{age}$ (SD = 5.5 m/s)
SS: $57.4 - 0.05 \times \text{age}$ (SD = 3.7 m/s)
MM: $69.0 - 0.18 \times \text{age}$ (SD = 3.4 m/s).

3 RESULTS

3.1 MEASURES OF LEAD EXPOSURE

3.1.1 Blood Lead

Mean blood lead concentrations were low for both the artillery and military intelligence groups, with no statistically significant difference between the two when all years of service were considered (Table 2, "All"). For persons with the lowest number of years of service, the concentrations were slightly higher in artillerymen, with the difference of borderline significance ($p = 0.08$).

A plot of Pb-B vs. length of service for both groups and each group individually (Figure 5) showed a slight increase in Pb-B with length of service when both groups were considered. This result was driven by the positive relationship between Pb-B and duration of service seen for the MI group by itself; no such relationship was found for the A group by itself. Possibly the artillerymen most recently in the artillery had a slight elevation in Pb-B due to recent firing of lead-containing charges, thus flattening the Pb-B vs. length of service relationship. For the MI personnel, the rise in Pb-B with length of service may have been a normal increase in Pb-B with age; members of subgroups with the longest length of service were about 10 years older than those with the shortest (Table 2, footnote a).

The distributions of blood lead concentrations for the two groups were not statistically different (Figure 6). However, in the Pb-B range of 3.0 μg/dL or greater, more subjects were artillerymen, and in the range of less than 3.0 μg/dL, more subjects were MI personnel.

3.1.2 Bone Lead

Table 3 shows the Pb/Ca XRF ratios for the artillery and control groups. No statistically significant difference was seen between the means, even when length of service was considered. In addition, regression analysis showed no significant relationship between bone lead concentration and length of service for both groups together or each group separately (Figure 7).

However, as with the values for Pb-B, there is an indication that the artillerymen with the shortest length of service (5–8 y) had Pb-S values somewhat higher than did the corresponding MI personnel (0.119 vs. 0.091; $p = 0.24$; Table 3). In addition, the values of Pb-S show an indication of difference in the distribution for the two groups, $p = 0.16$ for the Chi square test, with the MI personnel having more Pb-S values in the NS (not significant) range and the artillerymen having more values in the 0.15–0.20 range (Figure 8). It is possible that with larger numbers of persons in each group, these differences might become statistically significant.

3.2 MEASURES OF LEAD RESPONSE

3.2.1 Free Erythrocyte Porphyrin

As might be expected from the low levels of Pb-B and the small differences between groups with respect to measures of lead exposure, no significant differences were found in the FEP concentrations between the artillery and military intelligence groups, regardless of years of service (Table 4). In addition, using regression analysis, no significant relationship existed between FEP and length of service for either the combined or separate groups (Figure 9). Finally, the frequency distributions for FEP values were nearly identical (Figure 10).

3.2.2 Blood Pressure

No differences between groups were found for either systolic or diastolic blood pressure values, independent of years of service (Table 5). Using linear regression analysis, no significant relationship existed between either systolic or diastolic blood pressure and length of service for either the combined or separate groups (Figure 11). Finally, there was no preponderance of high blood pressure values among the artillerymen; i.e., the frequency distributions of blood pressure values were essentially the same for the artillery and military intelligence personnel (Figures 12 and 13).

3.2.3 Nerve Conduction Velocity

As shown in Tables 6 and 7, no significant differences were found between nerve conduction velocities of artillery and military intelligence personnel for three motor and three sensory nerves, independent of years of service. If anything, the NCV value for the sural sensory nerve in the artillerymen was a little higher than that of the military intelligence personnel. However, Table 8 shows that there was a significant effect of ethnic group on the NCV values of the sural sensory nerve; subjects with Hispanic surnames had the highest values. Consequently, the slightly higher value for the artillery sural sensory NCV can be accounted for by the make-up of the two groups: about one-third of the artillery personnel had Hispanic surnames, but none of the military intelligence personnel did.

Tables 9–11 are parallel to Tables 6–8, except that the NCV values have been expressed as Z scores, which correct for the decrease in NCV values expected with increasing age. These age-corrected NCV values lead to the same conclusion as the original data set: no significant effect of service in the artillery on NCV values, with subjects with Hispanic surnames having slightly but significantly higher NCV Z scores than the other ethnic groups (Table 11).

When NCV values were regressed against length of service, several nerves showed significant decreases with increasing length of service for both groups (Table 12). However, increasing length of service was accompanied by increasing age of the subject, and NCV values are known to decrease with age. When the NCV

values were converted to Z scores to correct for differences in age, no significant relationship was seen between length of service and Z score except for the sural sensory nerve, which still showed a decrease for the military intelligence, but not for the artillery, personnel (Table 13).

4 DISCUSSION

Blood lead concentrations were very low for all of the subjects in our study (Table 2), and length of service in the artillery did not increase these concentrations. Of all of the variables of exposure and response that were measured, only skeletal lead concentrations (Pb-S) showed signs of distinguishing between the artillery and military intelligence groups. While other variables showed identical frequency distribution patterns, the pattern for skeletal lead concentration was somewhat skewed, with more high values for the artillery and more low values for military intelligence (Figure 8), although with the small group sizes, the distributions were not statistically different. When broken down by years of service, the differences between the groups seemed to be greatest for the shorter-term artillerymen (Table 3). These results indicate the importance of measuring both blood lead concentrations as a measure of current exposure and bone lead concentrations as a measure of cumulative exposures in order to have a complete exposure assessment.

Although lead exposure has been associated with decreases in nerve conduction velocity (Se75, As80, Se80, Bo82, Si83, Co84, Je85) and increases in blood pressure (Ba83, Fi88), both cumulative (Pb-S) and recent (Pb-B) exposures in this study were low enough that such responses were not found in either group.

In our previous report (Bh93) on acute lead exposures among artillerymen firing high-lead charges from howitzers, we clearly showed that high air lead concentrations (300–400 $\mu g/m^3$) are present around artillery crew members when there is a light headwind moving the muzzle blast aerosol back toward the crew. Consequently, lead exposures during firing of these high-lead charges need to be restricted, but it appears as if the artillerymen in our study, especially the longer-term artillerymen, have not accumulated body burdens of lead that were strikingly different from those of the military intelligence controls and therefore probably had not fired many of the high-lead charges currently being tested.

A number of investigators have conducted studies of bone lead concentrations by in vivo x-ray fluorescence spectrometry (Pr84, So85, So86, So87, Ah80, Ch84, Wi86). Lead concentrations in the bones of environmentally exposed persons are typically 5–30 $\mu g/g$. Although we did not get to the point of convincingly converting our Pb/Ca XRF ratios to bone lead concentrations, most of our study subjects appear to be in this range, with mean Pb/Ca XRF ratios of 0.124 and 0.106 for the artillery and MI groups, respectively (Table 3); according to our phantom measurements, a ratio of 0.046 is equivalent to 8.3 μg Pb per gram of wet bone and a ratio of 0.145 is equivalent to 30 $\mu g/g$ (Figure 14). However, three artillery and three military intelligence personnel had Pb/Ca XRF ratios that were above 0.200, indicating that some of the subjects had had higher past exposures to Pb than others, with the higher values appearing to the same extent in each group.

Because there was no statistically significant difference in indices of lead exposure between the two groups under study, we combined the groups to look for potential correlations between lead exposures (as measured by Pb-S or Pb-B) and lead responses. We found no significant correlation between our two measures of exposure, blood lead concentration and bone lead concentration ($p > 0.05$). In

addition, there were no significant correlations between Pb-S and NCV for the six nerves under study. Systolic blood pressure showed no correlation with Pb-S, but diastolic pressure was positively correlated (BP_d = 19.8 + 0.465 Pb-S, R = 0.46, F = 10.5, p = 0.002). Further, there were no significant correlations between blood lead concentration and blood pressure, while some of the nerves (peroneal motor and sural sensory) showed significant decreases in NCV with increasing values of Pb-B ($p < 0.05$; Pb-B values were 2–11 μg/dL). Most likely these correlations occurred by chance alone because of the large number of correlations that we attempted to evaluate.

In summary, lead exposures were not significantly greater in artillerymen than in military intelligence personnel, and responses to lead exposure did not increase with increased length of service in either group. This does not mean that lead exposure is of no concern to artillerymen. First, group sizes were considerably smaller than originally planned for this study, and the indications of increased bone and blood lead concentrations reported here among younger artillerymen might have become statistically significant with larger group sizes. Second, the charges currently being tested for long-range firing have much more lead in them than did charges fired in the past, and our acute exposure study (Bh93) has shown that air lead concentrations during firing the current high-lead charges can be high (up to 600 $\mu g/m^3$).

5 REFERENCES

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6 FIGURES

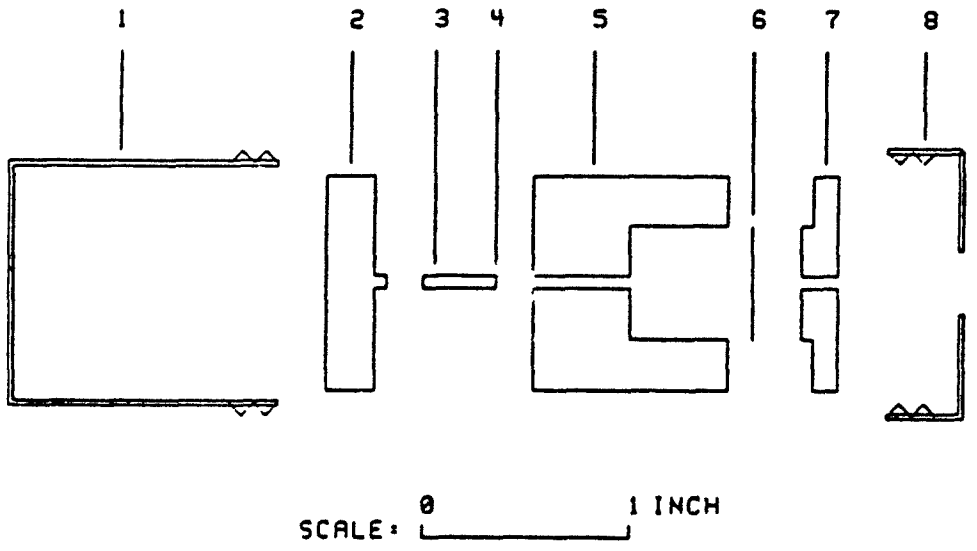
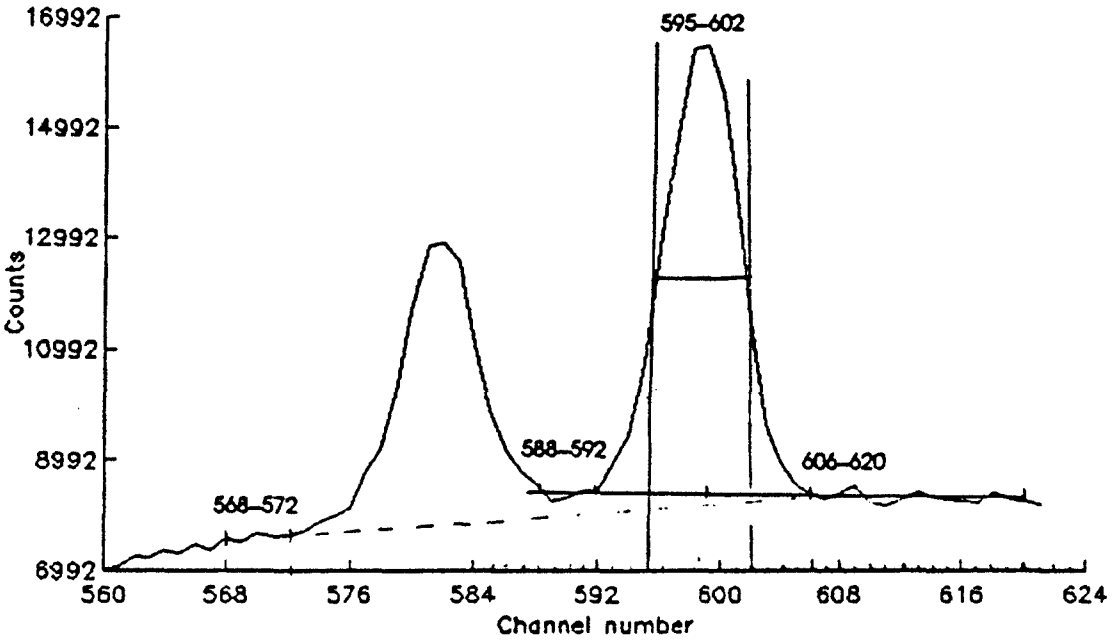


Figure 1 Diagram of ^{57}Co source. 1, steel cup; 2, back plate; 3, source rod; 4, source; 5, main holder; 6, tin filter; 7, collimator; 8, steel top cap.

Spectrum : calbon01.dat
Sample Title :



Start time : 19–Jul–90 12:08
Real time : 00:30:48.02
Live time : 00:30:00.00

Sample time : prior to 1980
Sample ID :
Sample type :

FWHM Parameters
Offset : 0.000000
Slope : 0.000000

Figure 2 XRF spectrum of plaster-of-paris tibia phantom containing 1000 pm Pb.

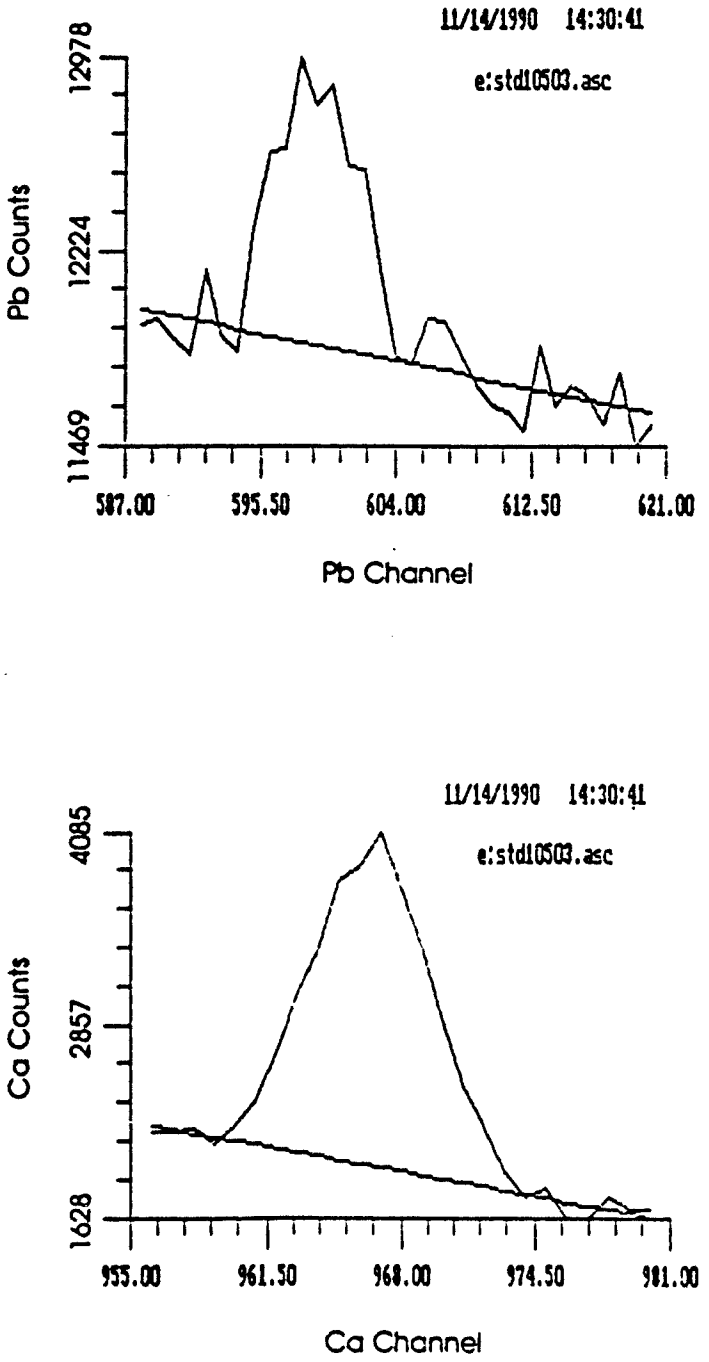
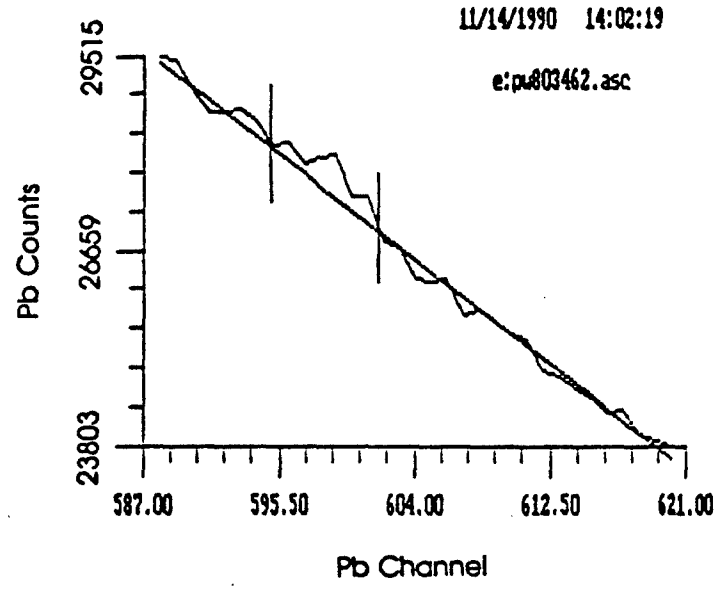


Figure 3 XRF spectrum showing lead region (upper) and calcium region (lower) for bone phantom containing 105 ppm Pb. Computer output showing the analyses of these regions, with the Pb peak/Ca peak ratio, is shown on the following page.

```
Program PbCaPeak run on 11/14/1990  11:07:38

Binary File: "ST010503.DAT"
Count Time:   30.00 minutes

------------------------ Pb ------------------------

Rg    CHANNEL      COUNT
 1        588      11938
 2        589      11964
 3        590      11884
 4        591      11819
 5        592      12153
 6        606      11961
 7        607      11956
 8        608      11824
 9        609      11706
10        610      11617
11        611      11604
12        612      11533
13        613      11856
14        614      11820
15        615      11700
16        616      11655
17        617      11552
18        618      11753
19        619      11469
20        620      11547

Rg Linear Regression    N= 20     INTERCEPT= 13409.43716
                                       SLOPE= -12.60418
                          CORRELATION COEFFICIENT=  0.74825

CHANNEL      COUNT        REG      COUNT-REG
  595        12322    11909.95      412.05
  596        12609    11897.35      711.65
  597        12620    11884.74      735.26
  598        12978    11872.14     1105.86
  599        12787    11859.53      927.47
  600        12877    11846.93     1030.07
  601        12555    11834.33      720.67
  602        12542    11821.72      720.28
              ---                    ----
SUM.....    191290    94926.69     6363.31
SD......    318.25      308.10      442.96
CPH.....   3376.33     3164.22

G4....   296.3621   Degrees of Freedom...  1  Chi-square prob... -4.00000000

------------------------ Ca ------------------------

Rg    CHANNEL      COUNT
 1        956      2179
 2        957      2189
 3        958      2195
 4        959      2112
 5        960      2224
 6        976      1632
 7        977      1628
 8        978      1756
 9        979      1682
10        980      1686

Rg Linear Regression    N= 10     INTERCEPT= 25630.06471
                                       SLOPE= -24.46529
                          CORRELATION COEFFICIENT=  0.96983

CHANNEL      COUNT        REG      COUNT-REG
  961        2397     2099.70      297.30
  962        2716     2075.21      640.79
  963        3067     2050.73     1016.27
  964        3330     2026.24     1303.76
  965        3779     2001.76     1777.24
  966        3882     1977.27     1904.73
  967        4085     1952.79     2132.21
  968        3714     1928.30     1785.70
  969        3357     1903.81     1453.19
  970        2891     1879.33     1011.67
  971        2464     1854.84      609.16
  972        2223     1830.36      392.64
  973        1944     1805.87      138.13
  974        1759     1781.39      -22.39
  975        1819     1756.90       62.10
              ---                    ----
SUM.....    43427    28924.50    14502.50
SD......    208.39      170.07      258.98
CPH.....   1447.57      964.15

G4....  2906.9543   Degrees of Freedom...  1  Chi-square prob... -4.00000000

(Pb-Peak/Ca-Peak) =   0.43877
```

Computer output for Figure 3.



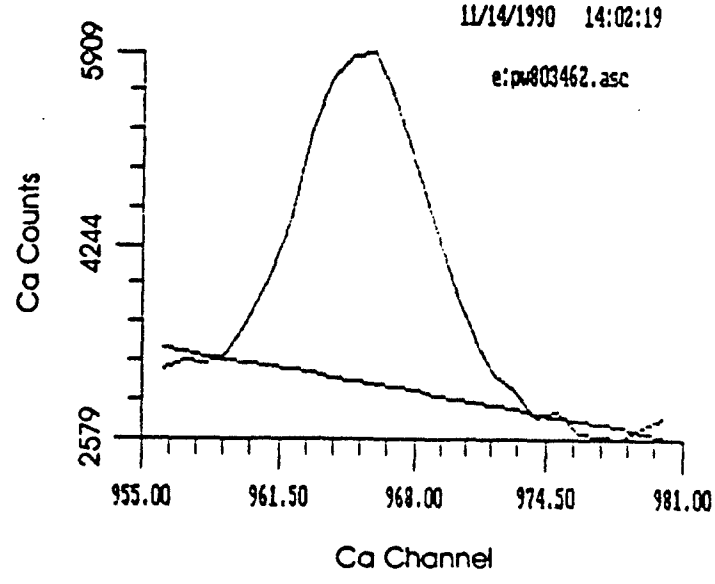


Figure 4 XRF spectra of Pb (upper) and Ca (lower) peaks from tibia of an artilleryman having a Pb/Ca XRF ratio of 0.102. Computer output showing the analyses of these regions, with the Pb peak/Ca peak ratio, is shown on the following page.

Program PbCaPeak run on 11/14/1990 13:53:40

Binary File: "P9003402.DAT"
Count Time: 30.00 minutes

Pb

Rg	CHANNEL	COUNT
1	588	29515
2	589	29453
3	590	29042
4	591	28691
5	592	28708
6	606	26244
7	607	25733
8	608	25614
9	609	25638
10	610	25451
11	611	25384
12	612	24913
13	613	24831
14	614	24642
15	615	24507
16	616	24308
17	617	24323
18	618	23964
19	619	23905
20	620	23803

Rg Linear Regression N= 20 INTERCEPT= 135790.66850
SLOPE= -180.89291
CORRELATION COEFFICIENT= 0.99815

CHANNEL	COUNT	REG	COUNT-REG
595	28220	28159.39	60.61
596	28272	27978.50	293.50
597	27969	27797.00	162.40
598	28025	27616.71	408.29
599	28097	27435.82	661.18
600	27477	27254.92	222.08
601	27442	27074.03	367.97
602	26783	26893.14	-110.14
SUM.....	222276	220219.10	2965.90
SD.....	471.46	469.27	665.20
CPM.....	7409.20	7340.34	

G4.... 9.6453 Degrees of Freedom... 1 Chi-square prob... 0.00189833

Ca

Rg	CHANNEL	COUNT
1	956	3181
2	957	3243
3	958	3238
4	959	3329
5	960	3592
6	976	2624
7	977	2608
8	978	2579
9	979	2588
10	980	2771

Rg Linear Regression N= 10 INTERCEPT= 33137.89804
SLOPE= -31.15196
CORRELATION COEFFICIENT= 0.90011

CHANNEL	COUNT	REG	COUNT-REG
961	3945	3200.86	744.14
962	4476	3169.71	1306.29
963	5230	3138.56	2091.44
964	5713	3107.41	2605.59
965	5895	3076.26	2818.74
966	5909	3045.10	2863.90
967	5505	3013.95	2491.05
968	4948	2982.80	1965.20
969	4388	2951.65	1436.35
970	3867	2920.50	946.50
971	3431	2889.34	541.66
972	3115	2858.19	256.81
973	3000	2827.04	172.96
974	2757	2795.89	-38.89
975	2803	2764.74	38.26
SUM.....	64982	44742.00	20240.00
SD.....	254.92	211.52	331.25
CPM.....	2166.07	1491.40	

G4.... 3733.5278 Degrees of Freedom... 1 Chi-square prob... -1.00000000

(Pb-Peak/Ca-Peak) = 0.18297

Computer output for Figure 4.

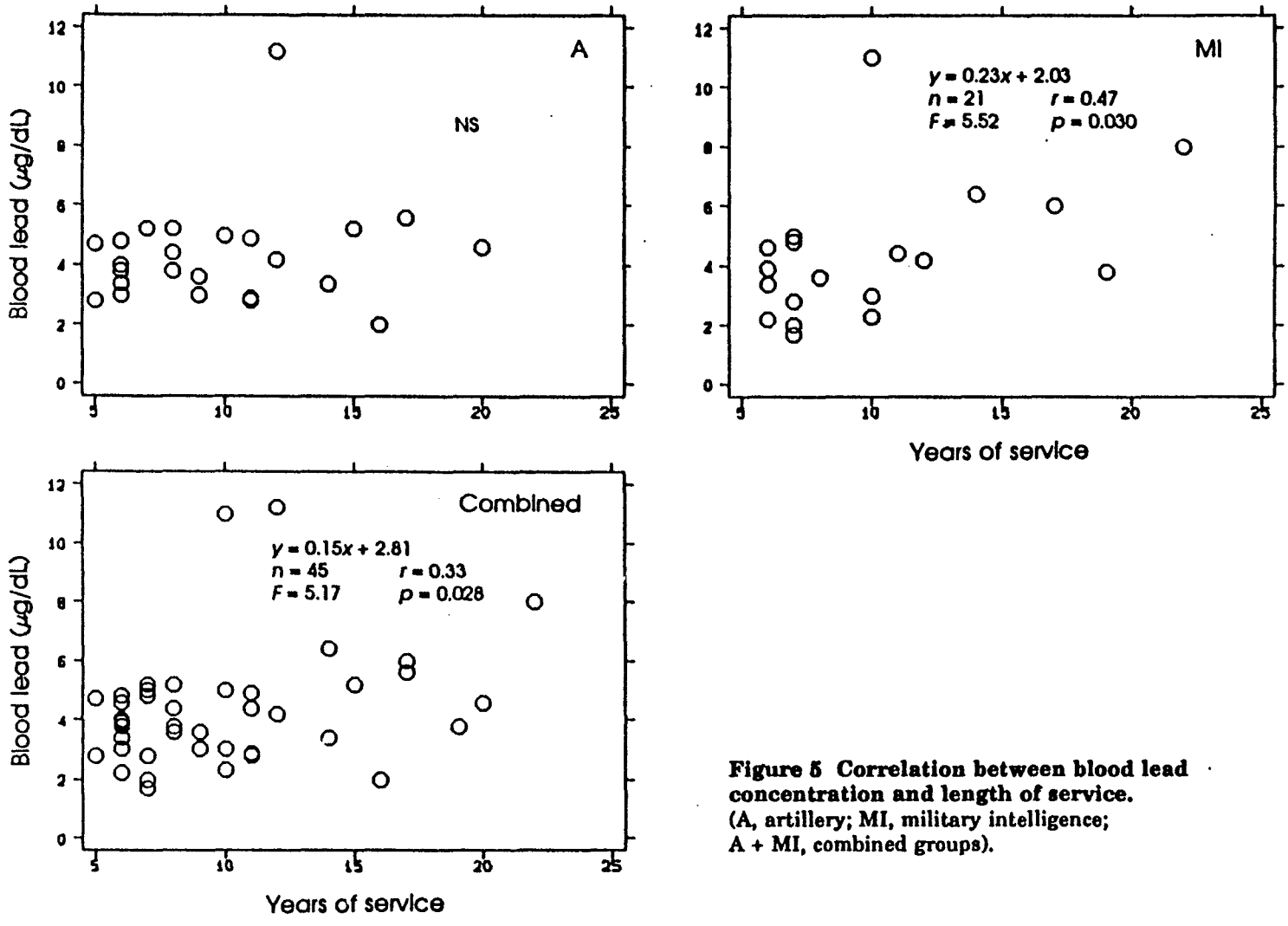


Figure 5 Correlation between blood lead concentration and length of service.
(A, artillery; MI, military intelligence; A + MI, combined groups).

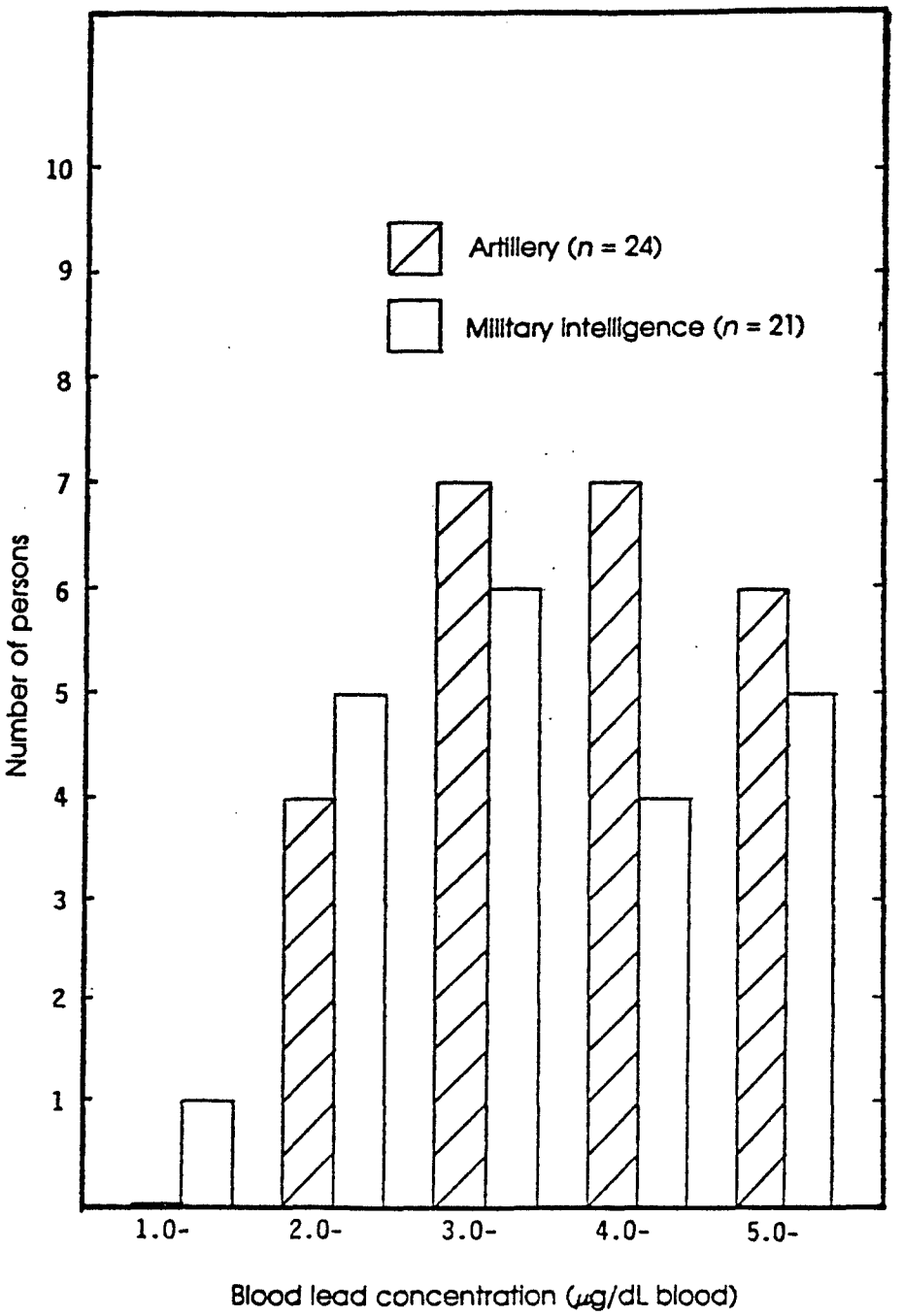


Figure 6 Frequency distribution of blood lead concentrations for artillery and military intelligence groups. (Distributions are not significantly different; Chi square test, $p = 0.38$.)

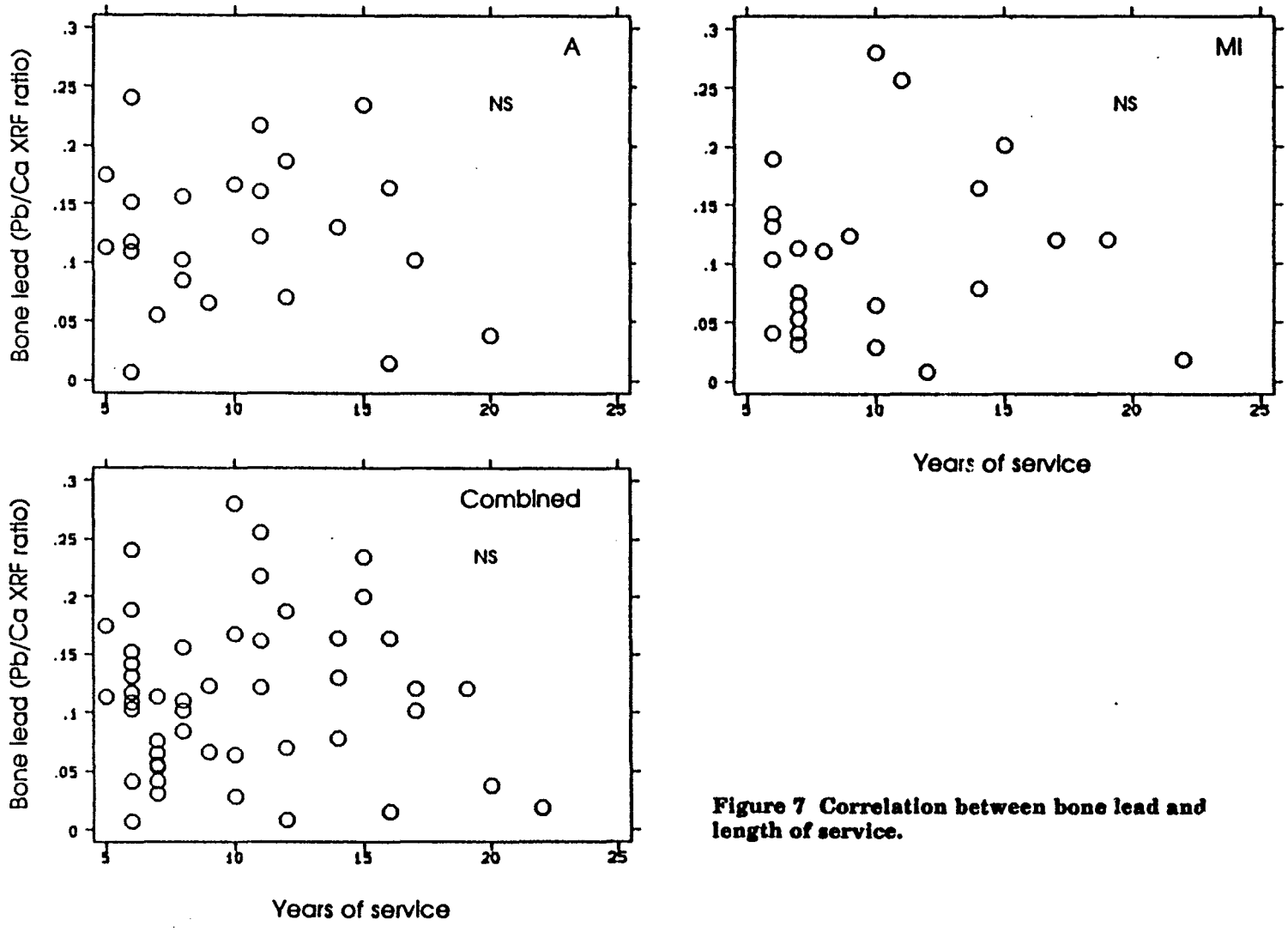


Figure 7 Correlation between bone lead and length of service.

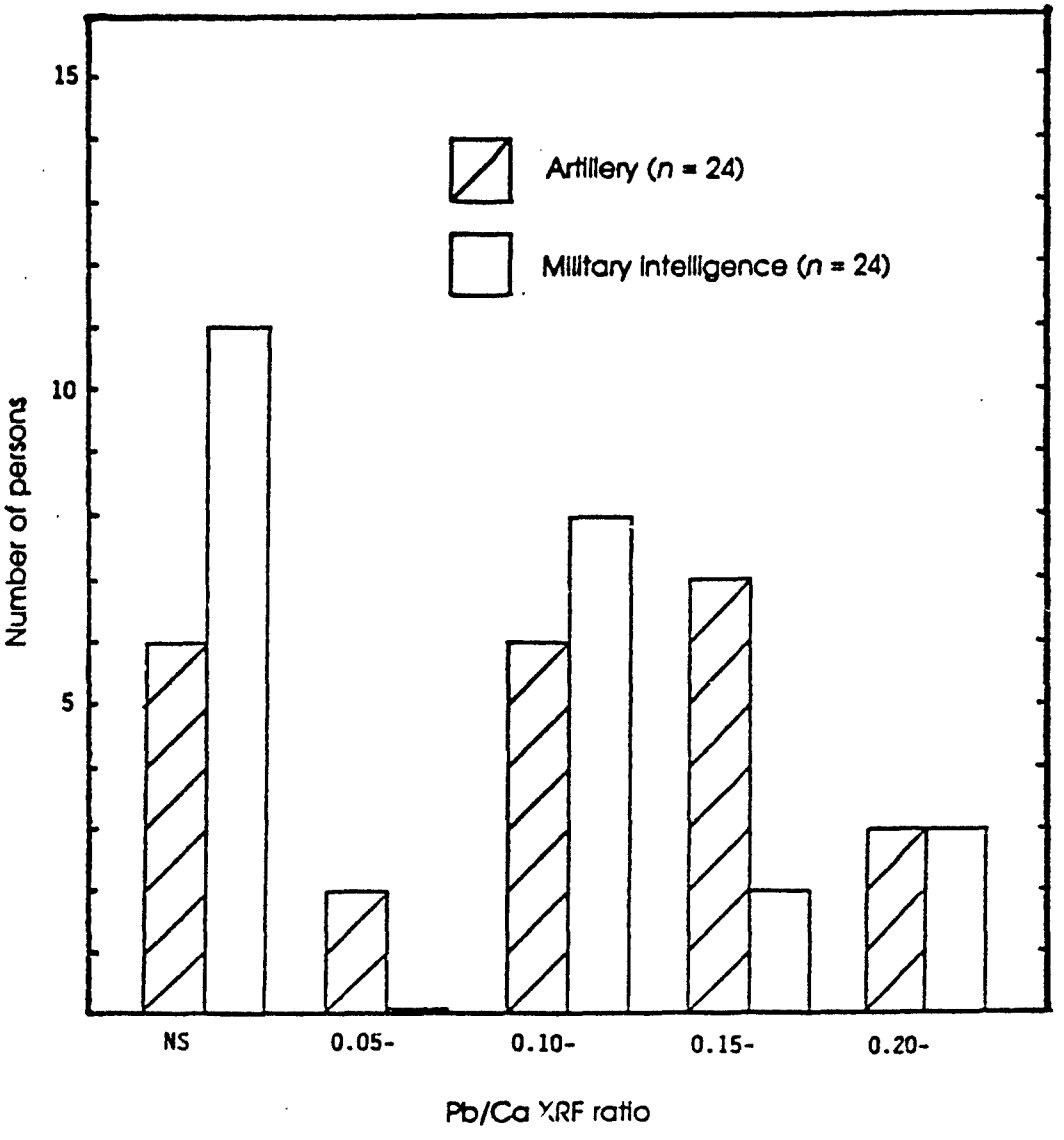
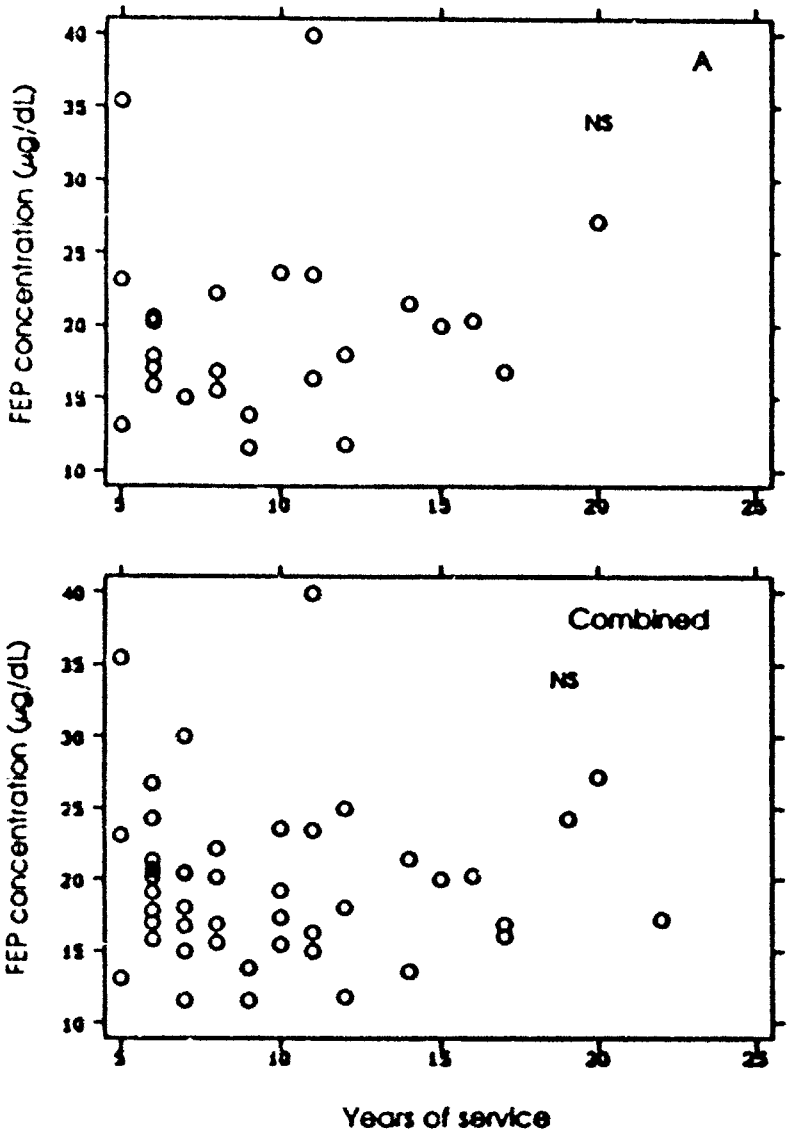


Figure 8 Frequency distribution of lead/calcium XRF ratios in tibia.
(Distributions are not significantly different; Chi square test, $p = 0.16$.)



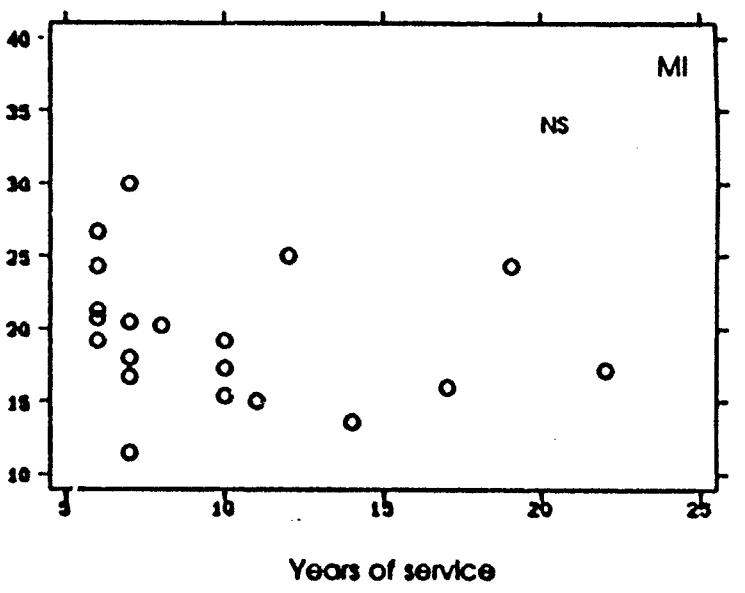


Figure 9 Correlation between free erythrocyte porphyrin concentrations and length of service.

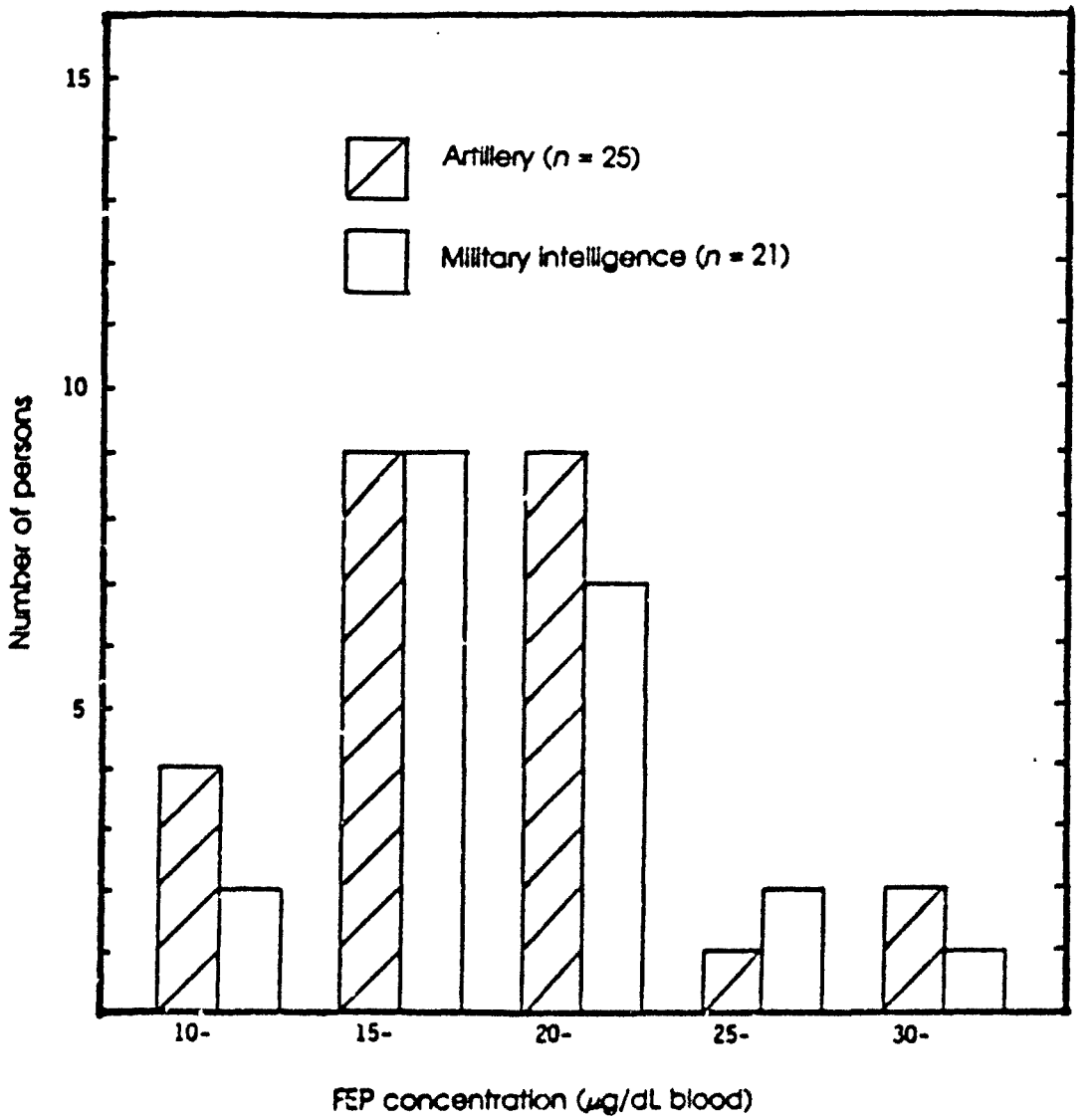


Figure 10 Frequency distribution of FEP concentrations.
(Distributions are not significantly different; Chi square test, $p = 0.56$.)

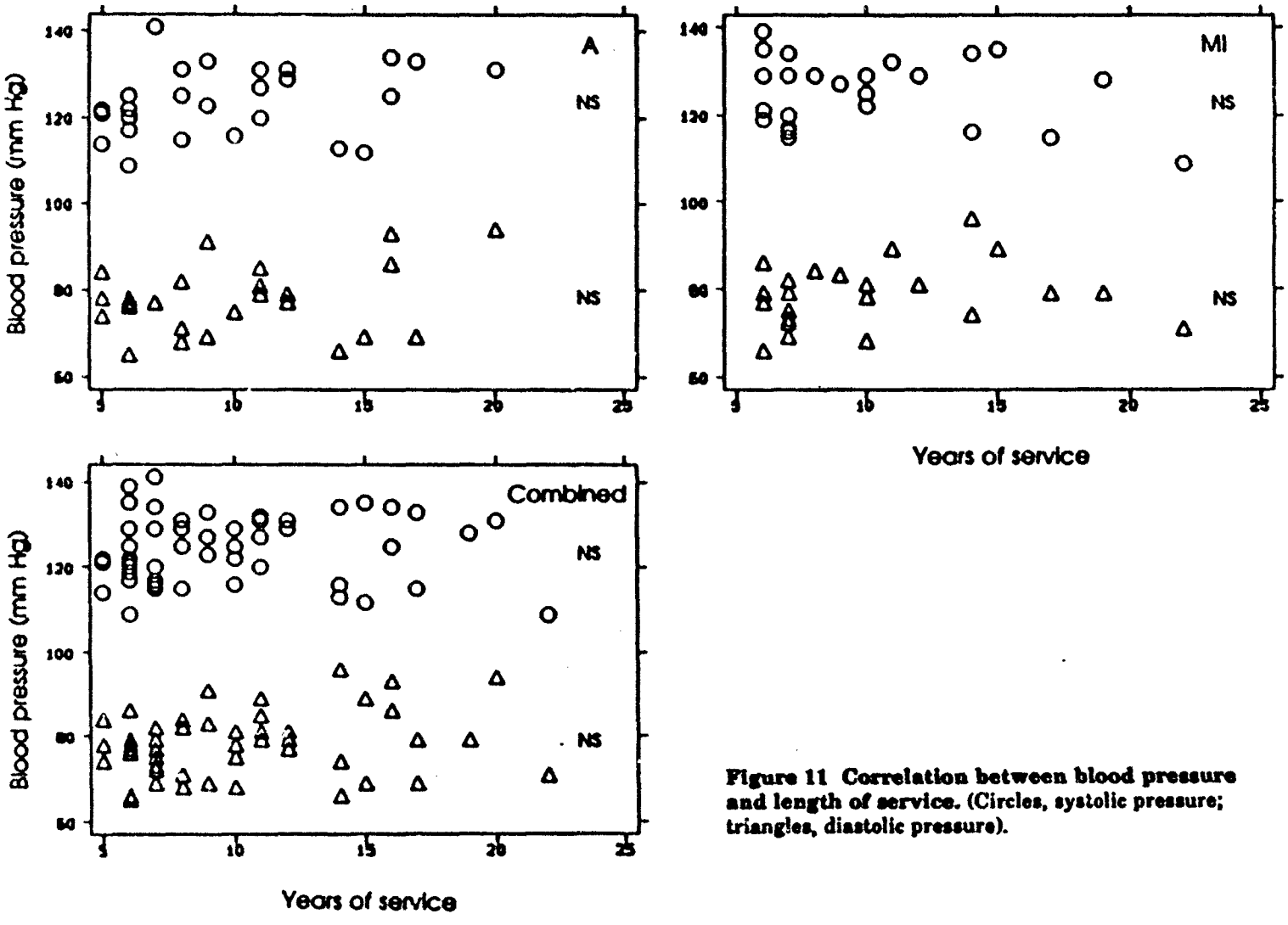


Figure 11 Correlation between blood pressure and length of service. (Circles, systolic pressure; triangles, diastolic pressure).

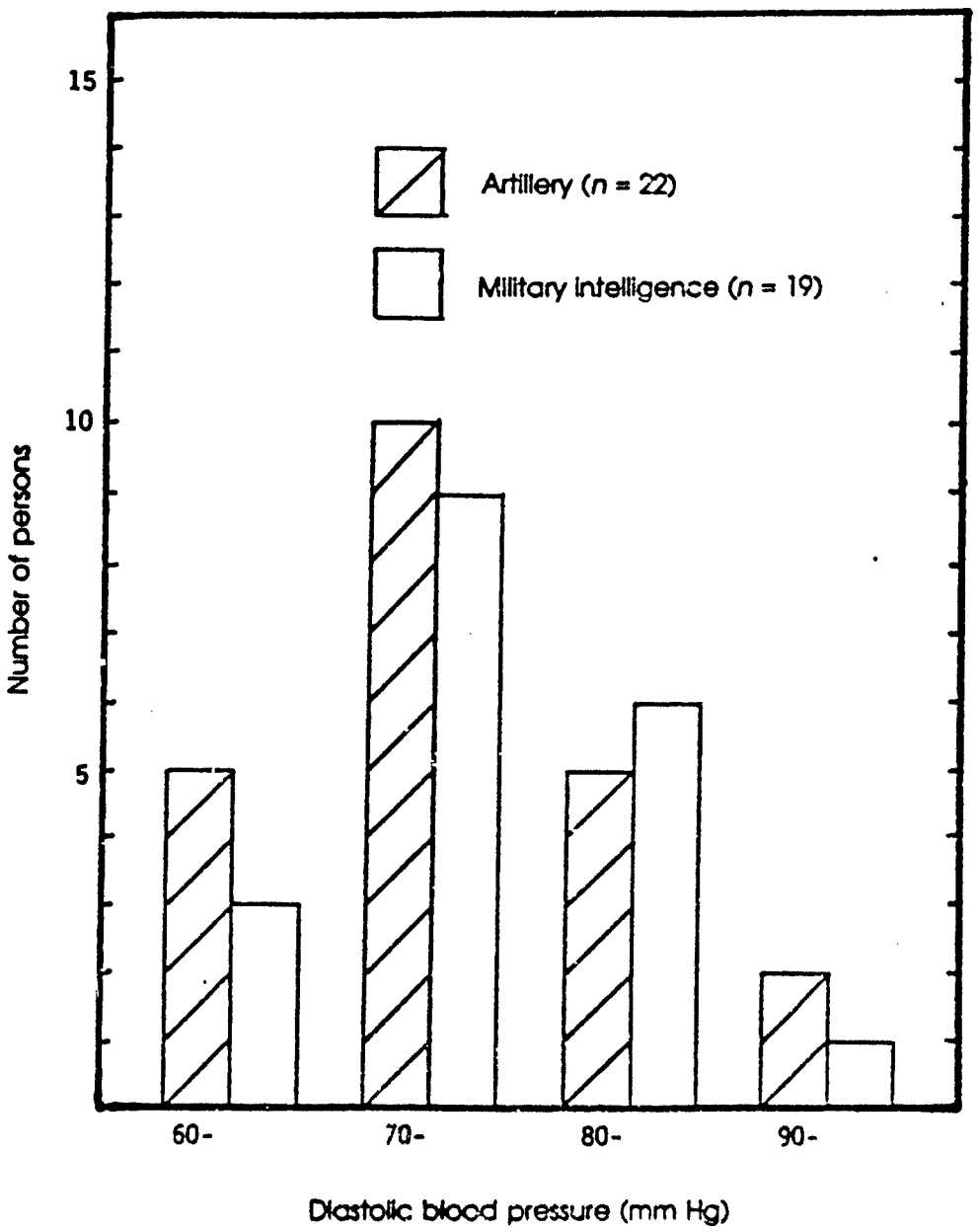


Figure 12 Frequency distribution of diastolic blood pressure.
(Distributions are not significantly different;
Chi square test, $p = 0.86$.)

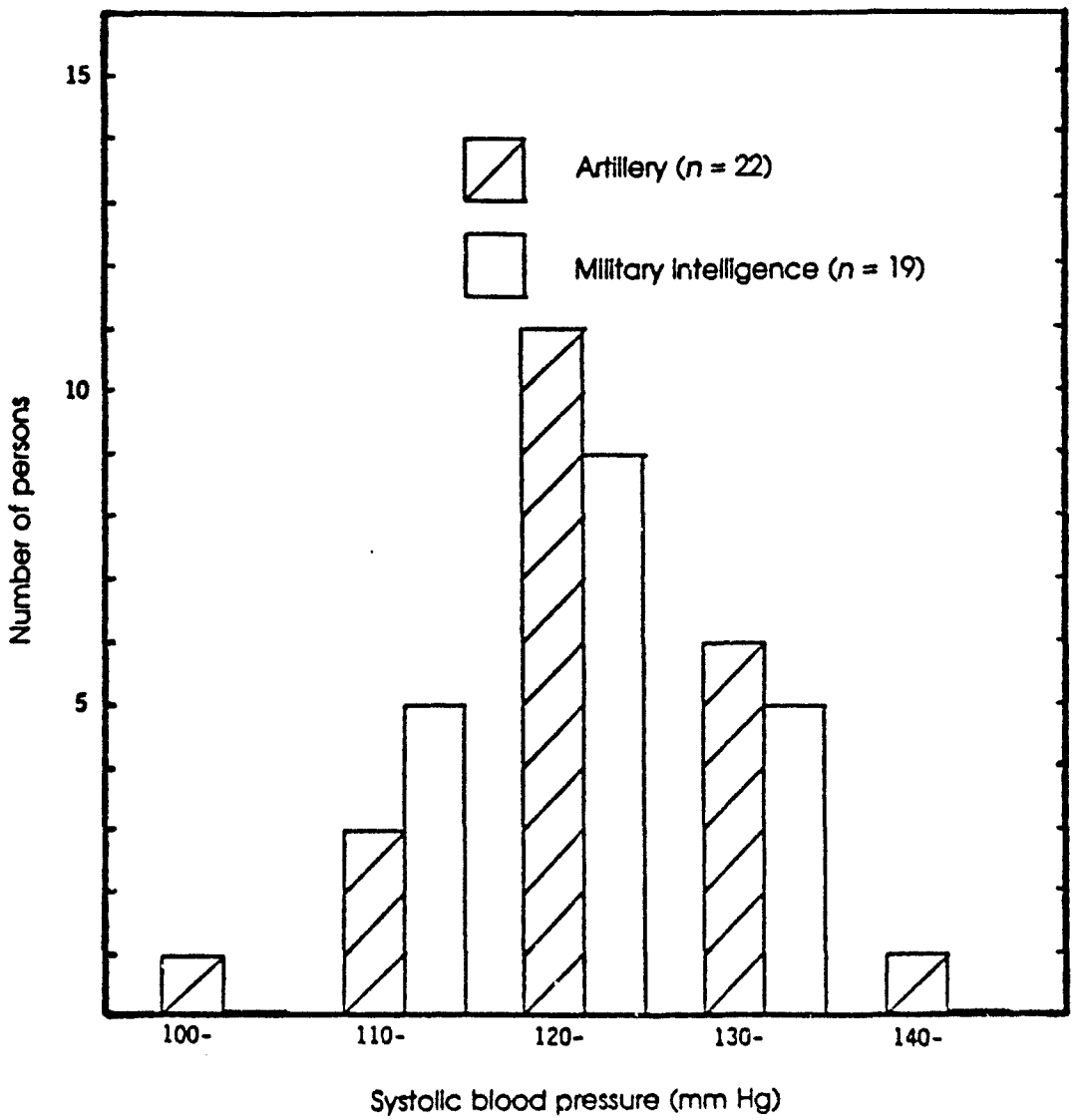


Figure 13 Frequency distribution of systolic blood pressure.
(Distributions are not significantly different; Chi square test, $p = 0.63$.)

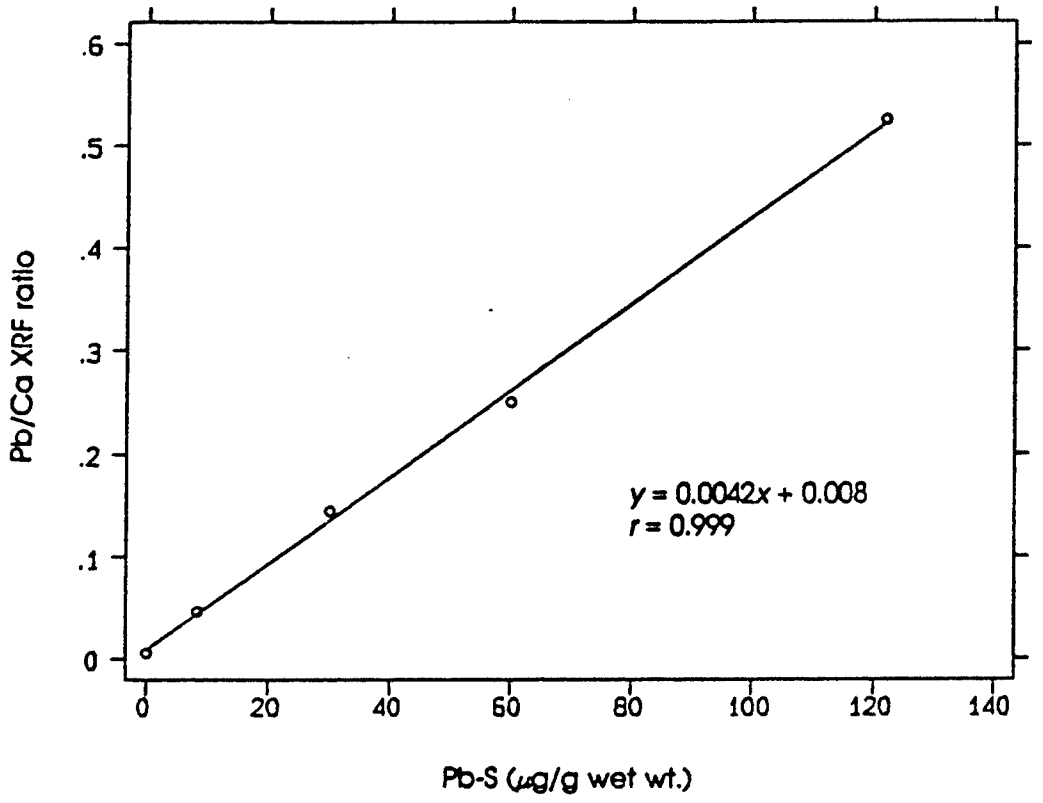


Figure 14 Standard curve for determination of lead in bone (Pb-S) by x-ray fluorescence spectroscopy.

7 TABLES

Table 1 Characteristics of the Study Population

Characteristic	Artillery			Mil. Intelligence		
		Percentage			Percentage	
	No.	Group	Cum.	No.	Group	Cum.
Age						
20–24	3	11.5	11.5	4	16.0	16.0
25–29	12	46.2	57.7	9	36.0	52.0
30–34	5	19.2	76.9	9	36.0	88.0
35–39	4	15.4	92.3	2	8.0	96.0
40–44	1	3.8	96.2	1	4.0	100.0
≥45	1	3.8	100.0	0	0	—
Total	26	100.0	—	25	100.0	—
Marital status						
Never	6	24.0	24.0	6	24.0	24.0
Married	18	72.0	96.0	15	60.0	84.0
Divorced	0	0	96.0	4	16.0	100.0
Separated	1	4.0	100.0	0	0	—
Total	25	100.0	—	25	100.0	—
Education						
G.E.D.	16	64.0	64.0	15	60.0	60.0
Some coll.	8	32.0	96.0	6	24.0	84.0
Coll. grad.	1	4.0	100.0	3	12.0	96.0
Grad. sch.	0	0	—	1	4.0	100.0
Total	25	100.0	—	25	100.0	—
Ethnicity						
White	9	36.0	36.0	22	88.0	88.0
Black	8	32.0	68.0	3	12.0	100.0
Hispanic	8	32.0	100.0	0	0	—
Total	25	100.0	—	25	100.0	—

Table 1 (Cont.)

Characteristic	Artillery			Mil. Intelligence		
		Percentage			Percentage	
	No.	Group	Cum.	No.	Group	Cum.
Smokers						
No	10	40.0	40.0	16	64.0	64.0
Yes	15	60.0	100.0	9	36.0	100.0
Total	25	100.0	—	25	100.0	—
Drinks (weekday)						
1 or less	14	56.0	56.0	17	68.0	68.0
2–12	10	40.0	96.0	8	32.0	100.0
13–24	0	0	96.0	0	0	—
25–48	1	4.0	100.0	0	0	—
Total	25	100.0	—	25	100.0	—
Drinks (weekend)						
1 or less	7	28.0	28.0	10	40.0	40.0
2–12	16	64.0	92.0	13	52.0	92.0
13–24	2	8.0	100.0	2	8.0	100.0
Total	25	100.0	—	25	100.0	—

Table 2 Blood lead concentrations

Time in service (y)	A		MI		p value[b]
	No. of observ'ns	Pb[a] (μg/dL)	No. of observ'ns	Pb[a] (μg/dL)	
All	24	4.3 ± 1.8	21	4.2 ± 2.2	0.90
5–8	11	4.1 ± 0.8	12	3.3 ± 1.2	0.08
9–14	9	4.6 ± 2.6	6	5.2 ± 3.2	0.67
15 or more	4	4.4 ± 2.6	3	5.9 ± 2.1	0.31

[a] Values are mean ± SD. Blood lead concentrations were determined by the method of Stoepler et al. (St78). The detection limit was 1.2 μg/dL (detection limit = 3 × SD of blank value). Ages for the years of service subgroup members were (mean ± SD):

A, 5- to 8-y group, 26.4 ± 2.8 y
9- to 14-y group, 32.0 ± 5.3 y
≥15-y group, 37.0 ± 1.7 y

MI, 5- to 8-y group, 26.9 ± 2.9 y
9- to 14-y group, 30.7 ± 4.3 y
≥15-y group, 38.5 ± 6.6 y

[b] p value for comparison of A vs. MI group by Student's t-test.

Table 3 Bone lead concentrations[a]

Time in service (y)	A		MI		p value[c]
	No. of observ'ns	Pb/Ca XRF ratio[b]	No. of observ'ns	Pb/Ca XRF ratio[b]	
All	24	0.124 ± 0.064	24	0.106 ± 0.072	0.63
5–8	11	0.119 ± 0.062	12	0.091 ± 0.048	0.29
9–14	8	0.140 ± 0.054	8	0.125 ± 0.101	0.72
15 or more	5	0.111 ± 0.091	4	0.115 ± 0.075	0.72

[a] Bone lead concentrations were determined in the tibia by in vivo x-ray fluorescence spectroscopy (XRF); see text for methods.

[b] Values are mean ± SD.

[c] p value for comparison of A vs. MI by Student's t-test.

Table 4 Free erythrocyte porphyrin (FEP) concentrations

Time in service (y)	A		MI		p value[b]
	No. of observ'ns	FEP[a] (μg/dL)	No. of observ'ns	FEP[a] (μg/dL)	
All	25	19.9 ± 6.7	21	19.6 ± 4.5	0.88
5–8	12	19.4 ± 5.9	12	20.8 ± 4.7	0.54
9–14	9	20.0 ± 8.8	6	17.6 ± 4.1	0.55
15 or more	4	21.1 ± 4.4	3	20.1 ± 4.5	0.60

[a] Values are mean ± SD. FEP concentrations in blood were determined by the method of Piomelli et al. (Pi73).

[b] p value for comparison of A vs. MI by Student's t-test.

Table 5 Blood pressure values[a]

Measurement	A		MI		p value[c]
	No. of observ'ns	Pressure[b] (mm Hg)	No. of observ'ns	Pressure[b] (mm Hg)	
Systolic					
All	26	124 ± 7	22	126 ± 7	0.57
5–8 y	10	123 ± 8	10	125 ± 9	0.60
9–14 y	9	124 ± 7	7	128 ± 9	0.25
15 or more y	3	129 ± 5	2	122 ± 9	0.28
Diastolic					
All	26	77 ± 8	22	79 ± 7	0.54
5–8 y	10	75 ± 6	10	76 ± 6	0.72
9–14 y	9	77 ± 8	7	82 ± 9	0.27
15 or more y	3	83 ± 13	2	79 ± 0	0.70

[a] Systolic and diastolic blood pressures were determined on three separate occasions in each individual, as described in the text.

[b] Values are mean ± SD.

[c] p value for comparison of A vs. MI by Student's t-test.

Table 6 Nerve conduction velocities (NCVs) for six nerves

	A		MI		
Nerve[a]	No. of observ'ns	NCV[b] (m/s)	No. of observ'ns	NCV[b] (m/s)	*p* value[c]
MM	26	57.6 ± 2.6	22	58.5 ± 2.5	0.20
UM	26	60.4 ± 4.2	22	61.2 ± 3.8	0.52
PM	25	48.0 ± 2.9	22	48.8 ± 4.0	0.56
MS	26	62.8 ± 3.3	22	62.4 ± 4.4	0.76
US	26	64.6 ± 4.0	22	64.2 ± 4.8	0.76
SS	24	38.1 ± 1.9	20	36.4 ± 3.1	0.07[d]

[a] MM = median motor, UM = ulnar motor, PM = peroneal motor, MS = median sensory, US = ulnar sensory, SS = sural sensory.

[b] NCV values are mean ± SD. They have been adjusted for differences in skin temperature according to the method of de Jesus et al. (De73), with arm nerves (MM, UM, MS, US) adjusted to 34 °C and leg nerves (PM, SS) to 33 °C.

[c] Values for A vs. MI were compared by ANOVA + Student's t-test, except when the variances in the samples differed according to Bartlett's test for homogeneity of variance, in which case nonparametric results from the Kruskal-Wallis test for two groups were used, as indicated. The p value when six pairwise comparisons are made (6 nerves) must be <0.01 to achieve an experimentwise error rate of $p < 0.05$ (Bonferroni correction for multiple comparisons, to protect against having a significant difference appear by chance alone).

[d] Kruskal-Wallis test.

Table 7 Nerve conduction velocities by years of service

Time in service (y)	A		MI		p value[b]
	No. of observ'ns	NCV[a] (m/s)	No. of observ'ns	NCV[a] (m/s)	
5–8					
MM[c]	12	58.7 ± 2.1	11	59.6 ± 2.4	0.62
UM	12	60.9 ± 3.6	11	61.6 ± 4.0	0.65
PM	11	48.1 ± 1.5	11	50.4 ± 2.5	0.02
MS	12	64.2 ± 2.2	11	64.2 ± 4.5	0.88[d]
US	12	65.7 ± 2.6	11	66.1 ± 6.4	0.85[d]
SS	12	38.5 ± 2.0	10	37.4 ± 2.0	0.22
9–14					
MM	9	58.1 ± 1.4	8	58.1 ± 2.0	0.99
UM	9	60.5 ± 4.4	8	61.2 ± 3.8	0.73
PM	9	49.0 ± 3.7	8	46.2 ± 4.8	0.20
MS	9	62.6 ± 3.1	8	59.8 ± 3.4	0.09
US	9	64.5 ± 4.6	8	62.9 ± 2.7	0.62
SS	7	37.8 ± 1.6	7	36.4 ± 2.2	0.19
15 or more					
MM	5	53.9 ± 2.0	3	55.7 ± 1.3	0.20
UM	5	59.2 ± 6.1	3	59.7 ± 3.9	0.91
PM	5	46.0 ± 3.0	3	49.8 ± 3.5	0.15
MS	5	59.6 ± 4.2	3	62.8 ± 4.0	0.33
US	5	62.2 ± 5.2	3	64.5 ± 2.1	0.50
SS	5	37.5 ± 2.4	3	32.9 ± 5.6	0.14

[a] NCV values are mean ± SD. They have been adjusted for differences in skin temperature according to the method of de Jesus et al. (De73), with arm nerves adjusted to 34 °C and leg nerves to 33 °C.

[b] See Table 6, footnote c. p must be <0.001 to achieve an experimentwise error rate of $p < 0.05$ (Bonferroni correction for multiple comparisons).

[c] MM = median motor, UM = ulnar motor, PM = peroneal motor, MS = median sensory, US = ulnar sensory, SS = sural sensory.

[d] Kruskal-Wallis test.

Table 8 Nerve conduction velocities of artillery personnel by ethnic group

Ethnic group	Age[a] (y)	Length of service[a] (y)	n	NCV[a,b] (m/s)					
				MM[c]	UM	PM	MS	US	SS
White	32.9 ± 6.8	11.2 ± 5.4	9	56.0 ± 2.7	58.9 ± 3.7	47.8 ± 3.0	62.9 ± 2.9	64.7 ± 3.7	36.9 ± 1.3
Black	28.7 ± 3.9	9.8 ± 4.0	8	57.9 ± 1.6	60.1 ± 5.5	46.5 ± 2.5	63.0 ± 4.5	64.7 ± 5.3	37.5 ± 1.9
Hispanic	29.0 ± 4.6	8.9 ± 3.4	8	58.0 ± 2.8	62.4 ± 3.2	49.4 ± 2.6	62.1 ± 3.0	64.7 ± 3.5	39.9 ± 1.4
p value[d]	0.22	0.55	—	0.10	0.25	0.13	0.86	0.89	0.003

[a] Values are mean ± SD.

[b] NCV values have been adjusted for differences in skin temperature according to the method of de Jesus et al. (De73), with arm nerves adjusted to 34 °C and leg nerves to 33 °C.

[c] MM = median motor, UM = ulnar motor, PM = peroneal motor, MS = median sensory, US = ulnar sensory, SS = sural sensory.

[d] See Table 6, footnote c. p must be less than 0.01 to achieve an experimentwise error rate of $p < 0.05$ (Bonferroni correction for multiple comparisons).

Table 9 Comparison of Z scores of NCVs obtained by age adjustment[a]

	A		MI		
Nerve	No. of observ'ns	Z score[b]	No. of observ'ns	Z score[b]	*p* value[c]
MM	25	−1.78 ± 0.68	22	−1.47 ± 0.66	0.12
MS	25	−1.23 ± 0.69	22	−1.30 ± 1.03	0.80
US	25	−1.48 ± 0.69	22	−1.56 ± 0.87	0.72
SS	23	−4.81 ± 0.52	20	−5.26 ± 0.80	0.03

[a] The Z score is the number of standard deviations that an individual's measured NCV value is from the predicted NCV value for that individual's age. If the Z score for A is significantly lower (more negative) than the one for MI, then the NCVs for A are significantly lower than those for MI, after considering all ages and making an adjustment for differences in age.

[b] Values are mean ± SD.

[c] p must be <0.01 to achieve an experimentwise error rate of $p < 0.05$ (Bonferroni correction for multiple comparisons).

Table 10 Z scores of NCVs obtained by age adjustment according to years of service[a]

Time in service (y)	A		MI		p value[b]
	No. of observ'ns	Z score[b]	No. of observ'ns	Z score[b]	
5–8					
MM	12	−1.61 ± 0.71	11	−1.33 ± 0.77	0.63
MS	12	−1.08 ± 0.51	11	−1.05 ± 1.05	0.71[c]
US	12	−1.42 ± 0.44	11	−1.51 ± 1.13	0.81[c]
SS	12	−4.74 ± 0.54	10	−5.02 ± 0.54	0.24
9–14					
MM	8	−1.60 ± 0.44	8	−1.57 ± 0.53	0.89
MS	8	−1.22 ± 0.73	8	−1.86 ± 0.87	0.13
US	8	−1.42 ± 0.89	8	−1.79 ± 0.47	0.32
SS	6	−4.89 ± 0.46	7	−5.25 ± 0.59	0.25
15 or more					
MM	5	−2.49 ± 0.53	3	−1.76 ± 0.63	0.12
MS	5	−1.62 ± 0.97	3	−0.70 ± 0.89	0.23
US	5	−1.71 ± 0.92	3	−1.17 ± 0.59	0.59
SS	5	−4.88 ± 0.64	3	−6.08 ± 1.58	0.17

[a] For explanation of a Z score, see footnote a, Table 9.

[b] Values are mean ± SD.

[c] p must be <0.004 to achieve an experimentwise error rate of p <0.05 (Bonferroni correction for multiple comparisons).

[d] Kruskal-Wallis test.

Table 11 Z scores of NCVs of artillery personnel according to ethnic group[a]

Nerve	Z score			p value[b]
	White	Black	Hispanic	
MM	−2.07	−1.73	−1.52	0.24
MS	−1.05	−1.25	−1.43	0.54
US	−1.40	−1.54	−1.52	0.91
S3	−5.11	−4.99	−4.34	0.003

[a] For explanation of Z score, see footnote a, Table 9.

[b] p must be <0.01 to achieve an experimentwise error rate of $p < 0.05$ (Bonferroni correction for multiple comparisons).

Table 12 Statistical parameters from analysis of relationships between length of service and NCV

Nerve	Combined (A + MI)			A			MI		
	p value	Pearson correl. coeff.	*n*	*p* value	Pearson correl. coeff.	*n*	*p* value	Pearson correl. coeff.	*n*
MM	0.000025	−0.57	48	0.00047	−0.64	27	0.012	−0.54	22
UM	0.18	−0.20	48	0.35	−0.19	27	0.34	−0.22	22
PM	0.068	−0.27	47	0.16	−0.29	26	0.24	−0.27	22
MS	0.0027	−0.43	48	0.0019	−0.58	27	0.18	−0.30	22
US	0.074	−0.26	48	0.043	−0.40	27	0.56	−0.14	22
SS	0.0068	−0.41	44	0.32	−0.21	25	0.013	−0.56	20

Table 13 Statistical parameters from analysis of relationships between length of service and Z scores for NCV[a]

Nerve	Combined (A + MI)			A			MI		
	p value	Pearson correl. coeff.	*n*	*p* value	Pearson correl. coeff.	*n*	*p* value	Pearson correl. coeff.	*n*
MM	0.054	−0.29	47	0.079	−0.36	26	0.32	−0.23	22
MS	0.23	−0.18	47	0.13	−0.31	26	0.71	−0.09	22
US	0.58	−0.08	47	0.31	−0.21	26	0.92	−0.03	22
SS	0.031	−0.33	43	0.64	−0.10	24	0.029	−0.50	20

[a] For an explanation of Z score, see footnote a, Table 9.

APPENDIX A:

Original Data Sets

Table A.1 Data on blood lead (Pb-B), free erythrocyte porphyrin (FEP), and blood pressure (BP) stratified by study group

Group	Rec. no.	First Year	Pb-B	FEP	BP1S	BP1D	BP2S	BP2D	BP3S	BP3D	Pb/Ca XRF
Art., 5–8 y											
	2	1982	4.4	22.4	118	62	110	70	118	72	0.084
	5	1982	5.2	15.0	142	94	144	68	136	68	NS
	11	1984	3.0	20.6	118	76	122	72	126	80	NS
	18	1984	3.8	17.0	122	78	120	74	118	78	0.152
	22	1982	3.8	16.8	142	94	128	78	124	74	0.156
	27	1985	4.7	23.1	116	80	122	68	126	76	NS
	33	1984	4.8	20.2	100	78	124	56	104	62	0.117
	35	1985	2.8	13.1	–	–	118	84	110	72	0.175
	37	1982	5.2	15.5	120	70	128	66	126	76	NS
	40	1985	–	35.4	114	88	126	74	126	90	0.113
	41	1984	4.0	15.8	120	76	126	76	128	82	0.109
	44	1984	3.4	17.8	–	–	118	76	116	80	0.241
Art., 9–14 y											
	3	1979	2.9	39.9	132	92	132	78	118	68	0.122
	17	1978	4.2	11.8	140	78	126	84	120	76	0.187
	29	1979	2.8	23.5	118	78	120	82	122	82	0.218
	31	1981	3.6	11.6	128	84	134	90	136	98	NS
	32	1980	5.0	23.6	124	72	106	70	118	82	0.167
	39	1979	4.9	16.3	132	80	128	88	134	88	0.161
	43	1978	11.2	18.0	142	76	126	78	124	76	0.070
	46	1981	3.0	13.8	120	68	130	58	118	80	–
	49	1976	3.4	21.5	108	58	120	76	110	64	0.130
Art., ≥15 y											
	9	1974	2.0	30.3	124	86	128	90	122	82	NS
	10	1974	–	–	128	94	–	–	140	92	0.164
	14	1970	4.6	27.2	144	100	122	88	128	94	NS
	42	1975	5.2	20.0	–	–	112	66	112	72	0.235
	51	1973	5.6	16.8	128	68	136	70	136	70	0.102

Table A.1 (Cont.)

Group	Rec. no.	First Year	Pb-B	FEP	BP1S	BP1D	BP2S	BP2D	BP3S	BP3D	Pb/Ca XRF
MI, 5–8 y											
	1	1983	5.0	20.5	120	78	110	78	114	64	NS
	6	1983	2.8	16.7	112	68	128	74	112	66	NS
	7	1984	4.6	26.7	114	80	124	78	118	74	0.103
	12	1983	2.0	20.4	136	80	128	68	138	72	0.113
	13	1983	4.8	18.0	–	–	126	80	132	78	NS
	20	1984	3.9	24.3	110	82	130	84	124	72	0.142
	23	1984	2.2	19.1	132	88	128	74	124	76	0.131
	30	1982	3.6	20.2	122	85	134	84	130	82	0.110
	34	1984	3.4	21.3	150	70	124	58	130	70	NS
	36	1983	2.0	11.5	118	80	–	–	122	84	NS
	47	1984	3.9	20.7	140	92	138	76	140	90	–
	48	1983	1.7	30.0	118	76	112	74	118	74	NS
MI, 9–14 y											
	8	1978	–	–	–	–	–	–	–	–	–
	15	1981	–	–	119	76	144	88	118	84	0.123
	16	1980	3.0	17.3	124	75	128	60	134	70	NS
	19	1980	11.0	19.2	120	78	130	84	126	82	NS
	25	1980	2.3	15.4	130	76	117	80	118	78	0.280
	26	1976	6.4	13.6	132	92	132	90	138	106	NS
	28	1976	–	–	116	74	–	–	–	–	0.164
	38	1978	4.2	25.0	138	78	124	80	124	86	NS
	50	1979	4.4	15.0	136	90	134	94	126	84	0.256
MI, ≥15 y											
	4	1971	3.8	24.3	130	82	128	78	126	78	0.120
	21	1975	–	–	138	88	132	90	–	–	0.201
	24	1968	8.0	17.2	–	–	110	66	108	76	NS
	45	1973	6.0	16.0	106	76	118	80	122	82	0.120

Table A.2 Data on NCVs without temperature adjustment

Group	Rec. no.	First Year	MCC1	UMC1	PMC1	MSC1	USC1	SSC1
Art., 5–8 y								
	2	1982	62.5	66.4	50.9	61.1	63.4	42.6
	5	1983	60.3	59.2	47.3	61.4	59.1	33.0
	11	1984	62.5	65.4	55.7	62.5	65.5	43.7
	18	1984	58.8	65.2	51.3	58.9	59.8	38.8
	22	1982	58.1	61.6	49.8	60.0	62.4	40.6
	27	1985	59.1	61.6	52.0	60.1	64.3	38.8
	33	1984	58.4	56.0	47.6	57.2	60.0	38.0
	35	1985	56.1	58.4	48.9	60.2	61.6	39.7
	37	1982	58.4	57.6	–	61.4	61.6	36.4
	40	1985	58.1	66.1	46.2	60.2	60.8	33.6
	41	1984	56.9	56.7	50.2	60.0	59.1	37.2
	44	1984	60.1	60.6	48.2	62.5	64.3	39.7
Art., 9–14 y								
	3	1979	61.3	63.4	49.4	61.3	63.3	37.2
	17	1978	57.6	60.7	43.7	58.5	62.5	36.4
	29	1979	58.8	63.4	57.1	57.6	62.5	41.6
	31	1981	57.2	61.6	46.0	59.2	62.4	35.0
	32	1980	57.9	64.3	46.2	57.8	62.4	33.6
	39	1979	59.2	52.3	57.4	60.1	56.8	43.7
	43	1978	54.5	53.9	45.1	54.6	54.5	–
	46	1981	61.3	61.5	54.0	63.7	62.5	40.6
	49	1976	53.8	61.5	51.2	52.9	54.4	–
Art., 15 y								
	9	1974	55.6	58.2	51.9	57.7	57.4	40.6
	10	1974	57.2	68.5	55.7	59.2	64.2	45.1
	14	1970	52.8	53.5	40.9	55.4	57.2	35.0
	42	1975	53.2	62.5	48.7	57.5	61.5	36.4
	51	1973	54.5	57.7	45.6	56.2	58.4	34.3

Table A.2 (Cont.)

Group	Rec. no.	First Year	MCC1	UMC1	PMC1	MSC1	USC1	SSC1
MI, 5–8 y								
	1	1983	–	–	–	–	–	–
	6	1983	63.6	69.0	54.9	64.9	66.0	40.6
	7	1984	58.9	66.3	47.6	61.2	64.3	39.4
	12	1983	58.3	56.2	50.6	60.3	57.5	33.0
	13	1983	61.2	63.3	49.4	62.5	66.0	37.2
	20	1984	61.2	63.4	53.2	58.8	65.5	39.7
	23	1984	60.1	59.1	51.4	62.5	59.1	35.7
	30	1982	61.2	60.6	49.8	57.7	55.8	36.4
	34	1984	55.0	60.7	46.7	54.0	59.2	35.0
	36	1983	58.1	55.4	53.8	60.2	52.0	37.2
	47	1984	58.8	59.7	48.7	60.0	61.5	–
	48	1983	58.4	63.3	52.7	59.3	63.3	37.2
MI, 9–14 y								
	8	1978	51.7	57.6	42.6	57.1	58.2	36.4
	15	1981	60.2	61.6	54.3	60.7	62.4	38.0
	16	1980	56.7	60.7	47.9	58.8	63.4	–
	19	1980	59.2	59.9	53.9	56.3	56.2	36.6
	25	1980	–	–	–	–	–	–
	26	1976	60.1	66.1	41.2	56.9	64.3	41.6
	28	1976	59.1	58.3	47.1	60.2	60.7	36.4
	38	1978	58.1	56.8	48.5	56.0	59.1	34.2
	50	1979	57.7	66.2	48.3	58.6	64.3	36.4
MI, ≥15 y								
	4	1971	57.9	64.2	53.7	60.0	63.3	38.0
	21	1975	–	–	–	–	–	–
	24	1968	53.7	54.9	43.0	51.7	56.5	24.3
	45	1973	58.0	62.5	49.4	62.5	59.0	32.4

Table A.3 Data on NCVs with temperature adjustment

Group	Rec. no.	First Year	MMC	UMC	PMC	MSC	USC	SSC
Art., 5–8 y								
	2	1982	60.9	64.7	47.7	60.3	62.6	40.6
	5	1983	60.2	59.2	49.9	64.8	62.4	36.6
	11	1984	62.5	65.4	49.7	65.1	68.3	41.9
	18	1984	58.7	65.2	50.0	66.2	67.2	40.2
	22	1982	56.8	60.3	46.7	60.7	63.1	38.1
	27	1985	57.8	60.3	49.0	63.7	68.1	36.8
	33	1984	60.3	57.9	47.6	65.6	68.8	40.8
	35	1985	55.6	57.9	45.7	63.8	65.3	38.7
	37	1982	58.3	57.6	–	62.4	62.6	36.8
	40	1985	57.8	65.8	47.7	67.9	68.6	35.4
	41	1984	55.7	55.5	49.1	64.7	63.7	37.8
	44	1984	60.3	60.8	46.0	65.4	67.3	38.5
Art., 9–14 y								
	3	1979	60.2	62.3	48.7	67.7	69.9	37.5
	17	1978	57.6	60.7	41.5	62.5	66.8	35.4
	29	1979	58.5	63.1	54.2	61.3	66.5	40.7
	31	1981	56.2	60.5	47.9	65.1	68.7	37.7
	32	1980	57.6	64.0	51.0	60.2	65.0	38.1
	39	1979	57.9	51.2	49.3	57.1	54.0	37.2
	43	1978	56.8	56.2	45.8	63.4	63.3	–
	46	1981	60.2	60.4	50.7	64.5	63.2	38.1
	49	1976	57.5	65.7	51.6	61.7	63.5	–
Art., ≥15 y								
	9	1974	53.5	56.0	49.5	57.9	57.6	40.7
	10	1974	57.2	68.5	45.5	55.8	60.5	37.3
	14	1970	52.3	53.0	43.0	61.5	63.5	38.2
	42	1975	52.5	61.7	48.7	66.0	70.6	37.1
	51	1973	53.8	56.9	43.5	56.6	58.8	34.1

Table A.3 (Cont.)

Group	Rec. no.	First Year	MMC	UMC	PMC	MSC	USC	SSC
MI, 5–8 y								
	1	1983	–	–	–	–	–	–
	6	1983	63.6	69.0	53.3	67.3	68.5	39.5
	7	1984	59.6	67.1	47.7	69.1	72.6	41.0
	12	1983	59.7	57.6	52.5	66.9	63.8	35.1
	13	1983	62.2	64.3	50.4	70.5	74.5	37.9
	20	1984	60.1	62.3	51.2	62.0	69.1	38.8
	23	1984	59.1	58.1	54.5	68.5	64.8	38.4
	30	1982	61.7	61.1	48.7	65.4	63.2	37.0
	34	1984	54.7	60.4	45.9	59.4	65.1	36.1
	36	1983	58.5	55.8	50.1	58.7	50.7	34.9
	47	1984	59.0	59.9	49.1	59.4	60.9	–
	48	1983	57.4	62.2	51.3	59.2	63.2	35.6
MI, 9–14 y								
	8	1978	55.2	61.5	41.1	59.0	60.1	34.7
	15	1981	59.6	61.0	52.0	63.8	65.6	39.4
	16	1980	56.7	60.7	46.9	58.5	63.1	–
	19	1980	61.2	61.9	50.4	66.2	66.1	35.0
	25	1980	–	–	–	–	–	–
	26	1976	59.8	65.8	37.5	56.8	64.2	39.7
	28	1976	56.6	55.9	45.7	58.4	58.9	34.6
	38	1978	57.6	56.3	49.5	57.1	60.3	35.6
	50	1979	57.7	66.2	46.3	58.8	64.5	35.7
MI, ≥15 y								
	4	1971	56.9	63.1	53.9	63.3	66.8	38.8
	21	1975	–	–	–	–	–	–
	24	1968	54.3	55.5	47.9	58.6	64.0	27.7
	45	1973	56.0	60.4	47.7	64.5	62.4	32.1

APPENDIX B:

Dosimetry Data Taken during XRF Measurements at ANL

Dosimetry Data Taken during XRF Measurements at ANL

Procedure

Thermoluminescent dosimeters (TLDs) were placed in various locations during a 1- or 2-h dose measurement time. Measurements were taken with two configurations: (1) no collimator on the source and (2) 3-mm collimator on the source, as would be used for the XRF measurements.

Configuration 1, with a wide beam, assured us that our dosimeters would not be placed at a location away from the beam for the purpose of measuring skin dose and bone entrance dose. Such a configuration would give an overestimate of marrow dose because of lack of collimation of the beam. Configuration 2, with the collimated beam, provided a realistic estimate of bone marrow dose.

With the uncollimated beam, we measured the air dose at a given distance from the source and the skin entrance, bone entrance, and bone exit doses using a leg phantom. With the collimated beam, we measured the bone marrow dose with the leg phantom.

The leg phantom consisted of a human tibia cut in half length-wise such that the marrow cavity could be visualized. The marrow cavity was filled with [illegible] marrow tissue-equivalent substance, and three TLDs (each 1 cm long) were placed end to end in the marrow cavity in the region of our XRF measurement. Another TLD was placed on the surface of the bone at the point where the x-ray beam would enter the bone. To include a leg-muscle-equivalent in our leg phantom, the human tibia, with the two halves bound together with rubber bands, was placed in a plastic beaker of water having a diameter about the same as the calf of the leg. The bone was placed near one edge of the beaker in a position analogous to the position of the human tibia in its surrounding muscle.

Finally, TLDs were placed at the right testis and the right ankle during a 30-min XRF measurement on an ANL subject.

Results

Measurement	Distance from front face of source (cm)	Dose per 30 min
Uncollimated beam		
Air	3	699 mR
Air	8	156 mR
Skin entrance (phantom)	4	616 mrem
Bone entrance (phantom)	4	396 mrem
Skin exit (back of leg, phantom)	4	30 mrem
Collimated beam		
Top marrow (phantom)	4	12 mrem
Middle marrow (phantom)	4	13 mrem
Bottom marrow (phantom)	4	10 mrem
Bone entrance (phantom)	4	351 mrem
Right testis (subject)	4	nd
Right ankle (subject)	4	nd

Note: The distance shown is the distance from the face of the source to the point at which the x-ray beam enters the front of the beaker for the phantom or the skin of the leg for the subject. An entry of "nd" means not detectable. To get the dose in millirem, we multiplied the dose in milliroentgens by 1.35.